ME571/Geol571 Geology and Economics of Strategic and Critical Minerals

Virginia T. McLemore

Commodities: Introduction

ASSIGNMENT

- **NEXT WEEK (Feb 12) IS Be, REE AFTER THAT (Feb 19, March 5, 12)**
- Barton and Young, S., 2002, Non-pegmatitic deposits of beryllium: mineralogy, geology, phase equilibria and origin: Reviews in Mineralogy and Geochemistry, v. 50, p. 591-691. http://www.geo.arizona.edu/~mdbarton/MDB_papers_pdf/Barton02_BeRiMG050.pdf
- McLemore, 2010, NMBGMR OF 533, http://geoinfo.nmt.edu/publications/openfile/downloads/OFR500-599/526-550/533/ofr_533.pdf

No class Feb 26—SME

- Midterm exam will be handed out next week—due March19 (e-mail)
- March 5—each of you will discuss SME or assigned papers
- Those who go to SME
  - Summarize 2 talks in the industrial minerals or mining & exploration sessions on REE, strategic minerals, industrial minerals, exploration (1 page summary to hand in and verbal summary)
  - My talk is on Tues at 2:00
- Those who stay home
  - Assigned articles on cathodoluminscence or REE mineralogy (1 pg summary, verbal summary)

- What products use critical and strategic minerals?
- Why are critical and strategic minerals important?
- What are some challenges in producing these minerals?

The Changes in American Lifestyle

1776 vs. 2005

The Minerals We Use In Our Everyday Lives

From the Mineral Information Institute
An Affiliate of the Society for Mining, Metallurgy and Exploration Foundation

Sources: U.S. Bureau of Mines, U.S. Geological Survey, Statistical Abstracts of the USA

In 1776

Average Life span was about 33 years
Population was 2.8 million

At the time of the Revolutionary War, about 1,200 pounds of minerals were needed each year, for every person in the United States.

— *1975, U.S. Bureau of Mines*

Cement (lime)	12	Sand, gravel & stone	1,000
Clay	100	Lead	2
Coal	40	Potash	1
Copper	1	Sulfur	1
Pig Iron	20	Zinc	0.5
Salt	4		

43,200 lbs. in a Lifetime

By 1850, life had improved (a little)

	1776	1850
Population (millions):	2.8	23
Lifespan (years):	33	43
Annual consumption mined material (lbs.):	1,200 (est.)	unknown
Houses (millions):	unknown	3.4

Lifestyle in 1850:

In Charleston, 62% died by the age of 40 — 25% by the age of 5

Boston averaged 8.6 people per house

Energy consumption was 10 times that of 1776— 90% from wood, 10% from coal

In 1800: Boston to New York took 3 days by stage coach

At the turn of the century, we were an emerging world power

	1776	1850	1900
Population (millions):	2.8	23	76
Lifespan (years):	33	43	47.3
Annual consumption mined material (lbs.):	1,200 (est.)	unknown	7,714
Houses (millions):	unknown	3.4	16
Motor Vehicles	--	--	8,000

Lifestyle in 1900:

1.5 million telephone instruments

Avg. per capita consumption of liquors was 17.68 gallons

Dozen eggs cost 14¢

2.8 million miles of Public Road (1923)

The Glorious 50s

	1776	1850	1900	1950
Population (millions):	2.8	23	76	152
Lifespan (years):	33	43	47.3	68.2
Annual consumption mined material (lbs.):	1,200 (est.)	unknown	7,714	25,938
Houses (millions):	unknown	3.4	16	42.5
Motor Vehicles	--	--	8,000	149 million

Lifestyle in 1950:

Houses: 983 sq. ft., averaged 4.6 rooms 5% had no electricity
71% had inside toilet — 15% had no kitchen sink
96% had a radio — 12% had a TV
50% had central heating — 1/2 with coal, 1/4 each fuel oil or gas
53% no garage/carport
Average Value= $10,800 Avg. Monthly Rent= $46
Average Income was $2,992 Bread cost 14¢ a loaf

1776 vs. 2005

	1776	1850	1900	1950	2005
Population (millions):	2.8	23	76	152	295
Lifespan (years):	33	43	47.3	68.2	77.8
Annual consumption mined material (lbs.):	1,200 (est.)	unknown	7,714	25,938	47,502
Houses (millions):		3.4	16	42.5	112
Motor Vehicles	--	--	8,000	149 million	237 million

Lifestyle in 2005:

New Houses averaged: 2,400 sq. ft., 88% with 3 or more bedrooms

95% with more than 2 bathrooms — 76% had central air conditioning

Average Value= $258,000 — 2 million new units were built

Nearly 240 million motor vehicles and 4 million miles of roads (2.6 million hard-surfaced).

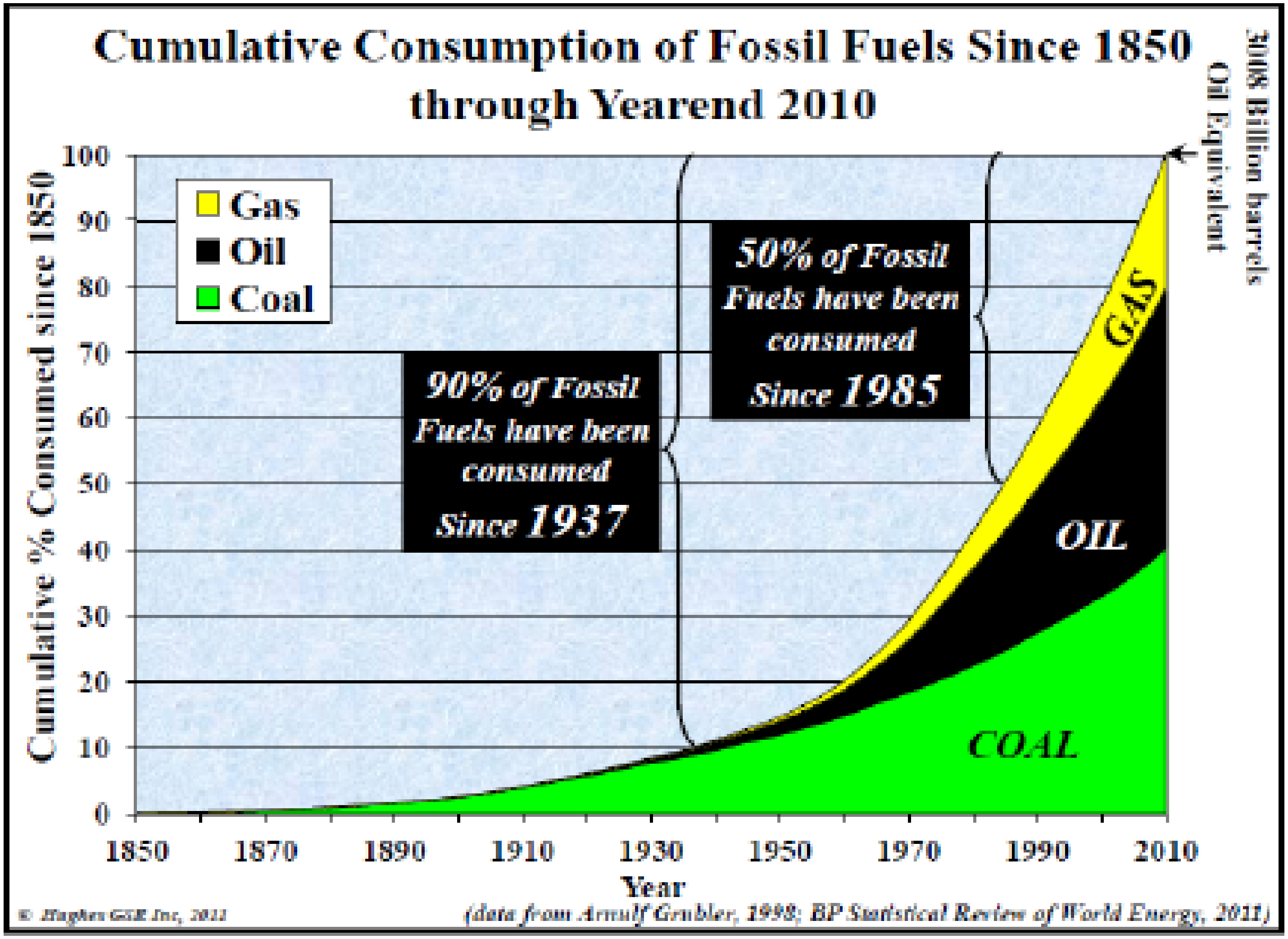
18,500 airports, serving 281,000 non-military airplanes, flying 5.5 billion miles in 8 million trips for 550 million passengers.

62% of homes owned a computer — the Internet and computers used up to 2 percent of total U.S. electricity consumption. Ordering a book on-line burned an ounce of coal.

This change in life style results in new products, which depends upon more and new minerals!

These minerals will be mined from traditional and new countries and types of deposits.

Fossil Fuels – a similar picture to mineral resources

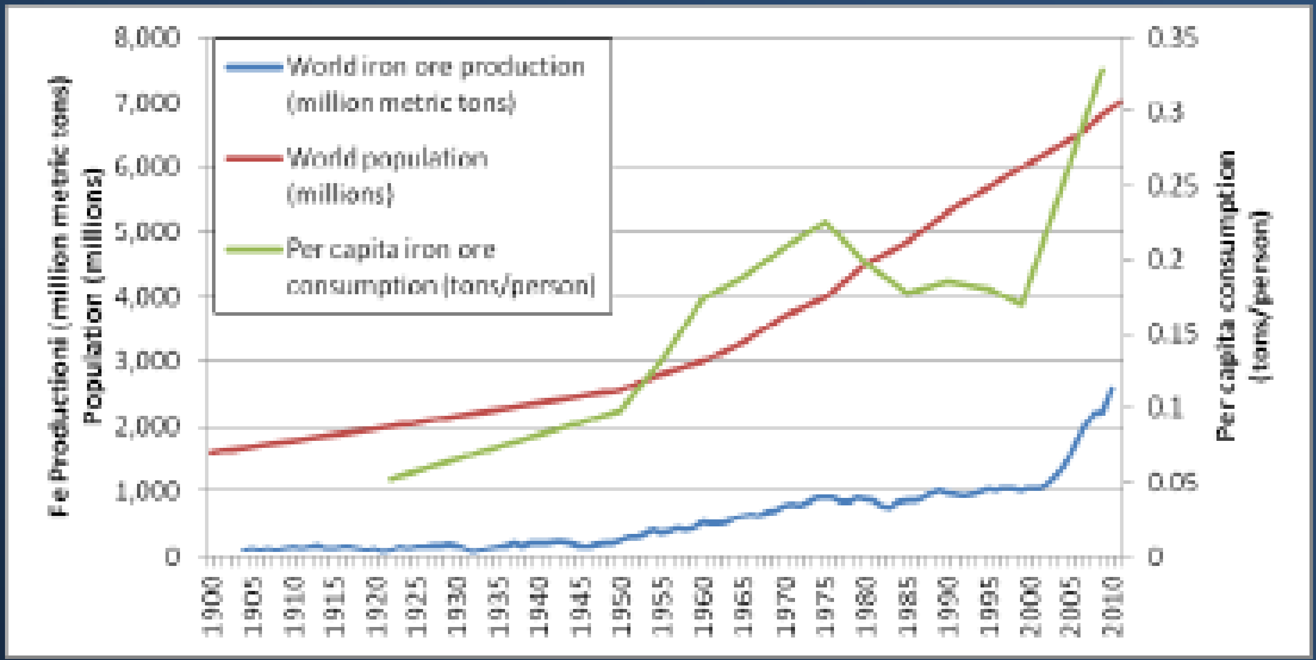


J. David Hughes, 2012
(http://www.eeb.cornell.edu/howarth/HUGHES%20Cornell%20Ithaca%20May%202%202012.pdf)

USGS

Mineral Resources – The Big Picture

Global Trends in Population, Iron Ore Production, & Consumption, 1990-2011



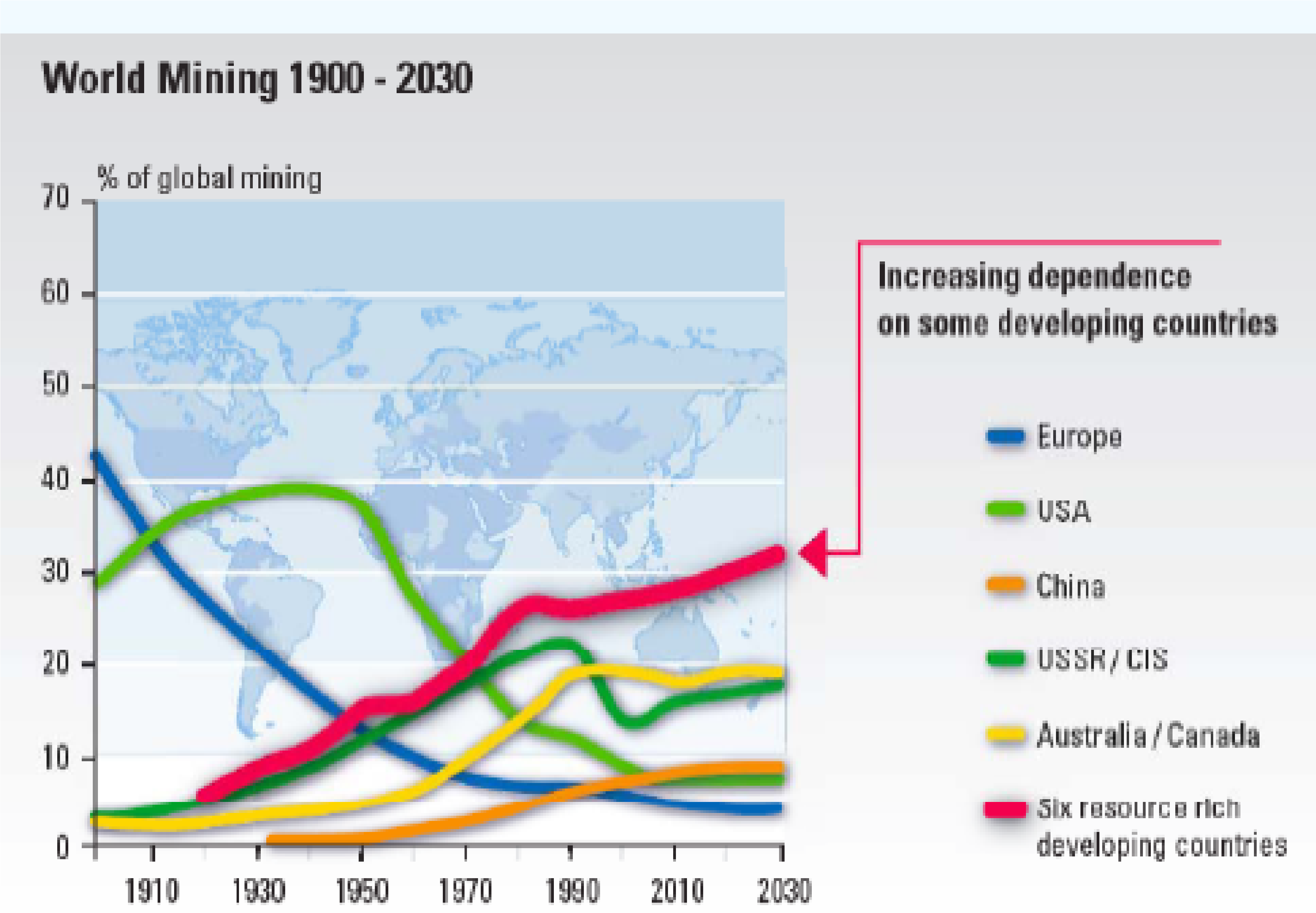
Production data from USGS

~4X more population than 100 years ago

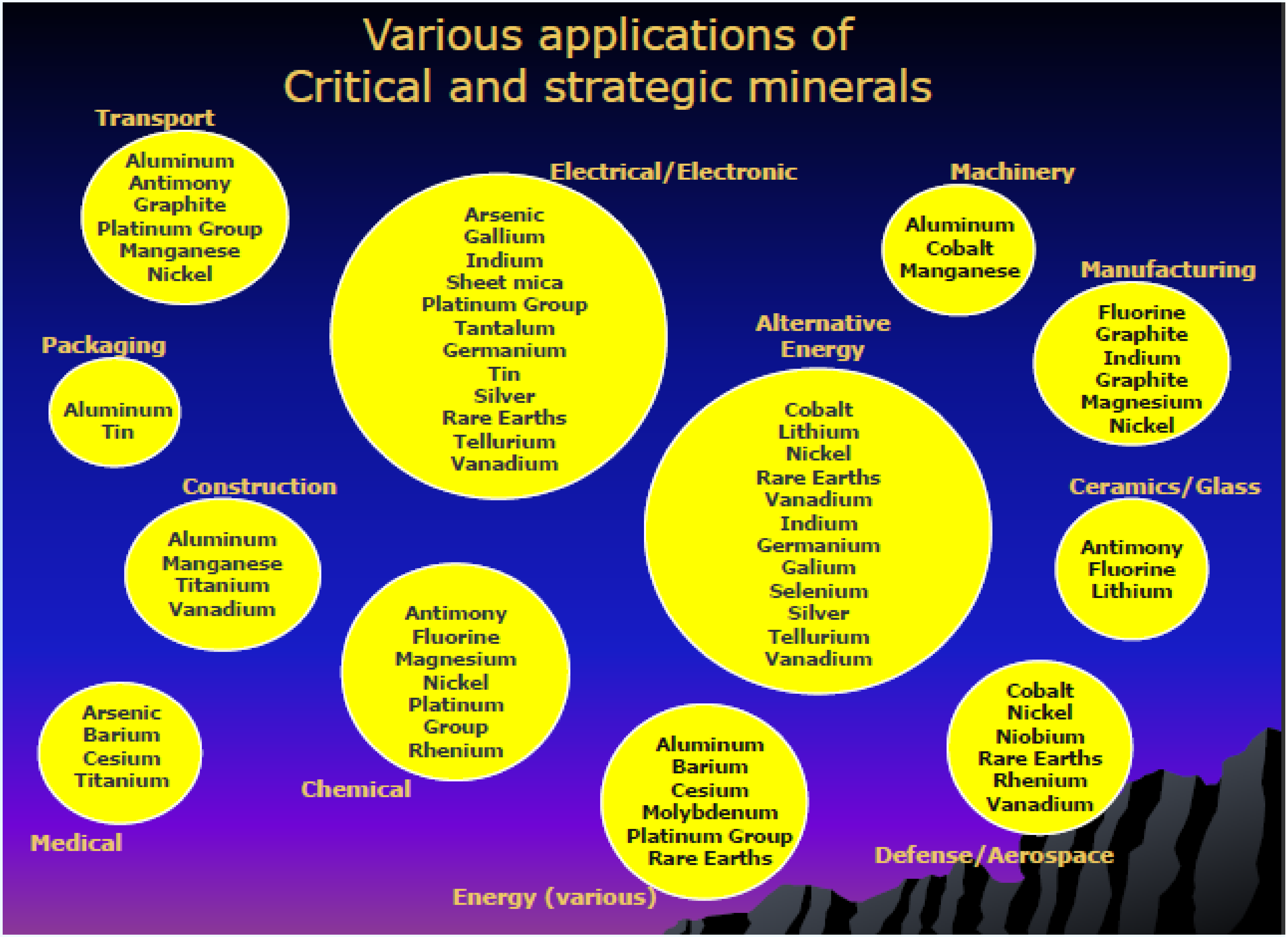
~6X more per capita iron consumption than 100 years ago

~26X more iron ore production than 100 years ago

USGS



Sources: Ericsson, Raw Materials Data 2005; Sames, 1975


Various applications of
Critical and strategic minerals
Transport
Aluminum
Antimony
Graphite
Platinum Group
Manganese
Nickel
Electrical/Electronic
Arsenic
Gallium
Indium
Sheet mica
Platinum Group
Tantalum
Germanium
Tin
Silver
Rare Earths
Tellurium
Vanadium
Machinery
Aluminum
Cobalt
Manganese
Manufacturing
Fluorine
Graphite
Indium
Graphite
Magnesium
Nickel
Packaging
Aluminum
Tin
Alternative Energy
Cobalt
Lithium
Nickel
Rare Earths
Vanadium
Indium
Germanium
Galium
Selenium
Silver
Tellurium
Vanadium
Construction
Aluminum
Manganese
Titanium
Vanadium
Ceramics/Glass
Antimony
Fluorine
Lithium
Chemical
Antimony
Fluorine
Magnesium
Nickel
Platinum
Group
Rhenium
Medical
Arsenic
Barium
Cesium
Titanium
Energy (various)
Aluminum
Barium
Cesium
Molybdenum
Platinum Group
Rare Earths
Defense/Aerospace
Cobalt
Nickel
Niobium
Rare Earths
Rhenium
Vanadium

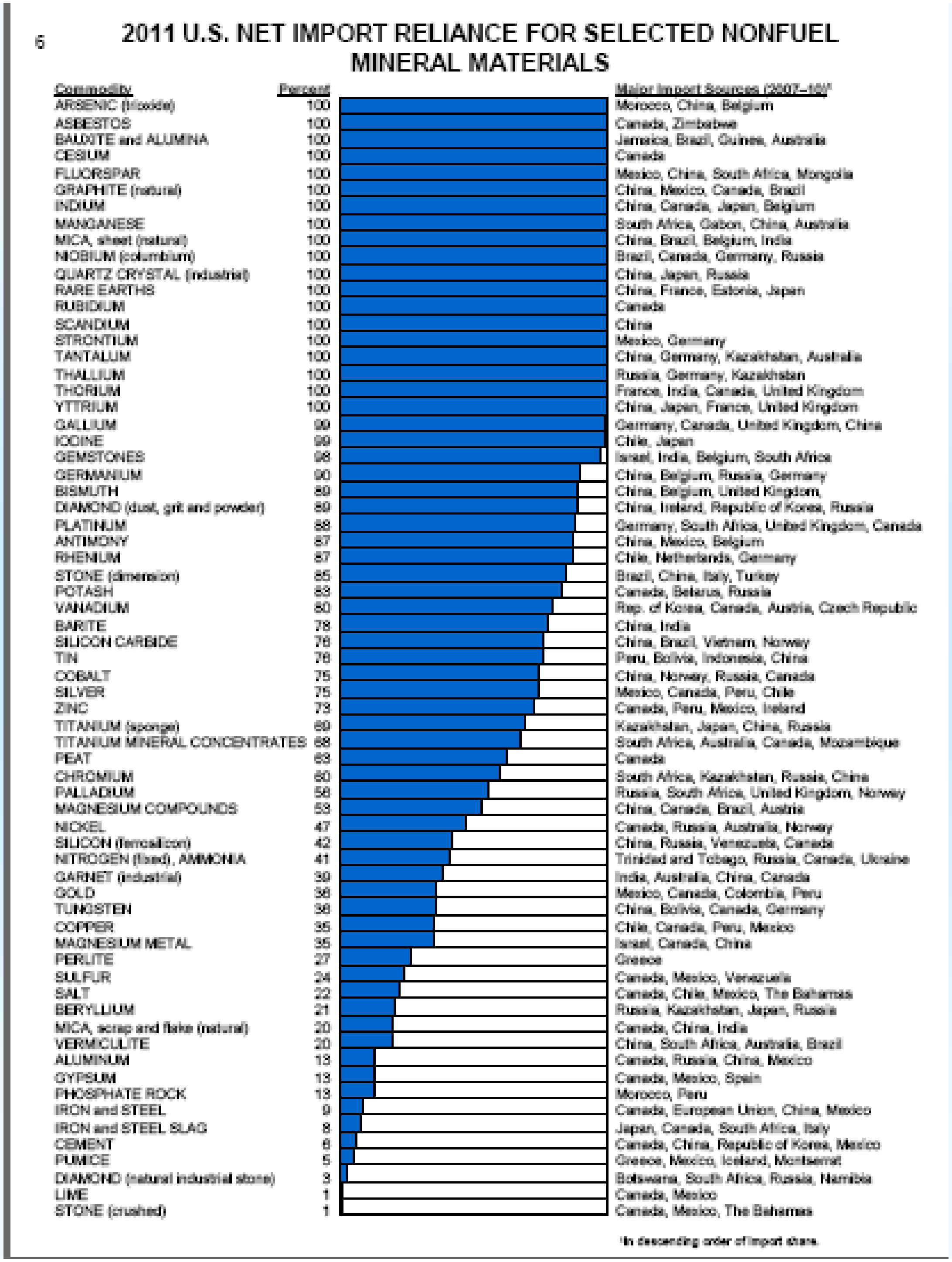
Usage of significant metals in 2030 by SET-Plan technology (% of 2010 world supply)

Metal	Solar PV	Wind	Nuclear	CCS	Total
Tellurium	50.4%	×	×	×	**50.4%**
Indium	18.0%	×	1.4%	×	**19.4%**
Tin	9.6%	×	0.02%	×	**9.6%**
Hafnium	×	×	7.0%	×	**7.0%**
Silver	4.8%	×	0.4%	×	**5.2%**
Dysprosium	×	4.0%	×	×	**4.0%**
Gallium	3.9%	×	×	×	**3.9%**
Neodymium	×	3.8%	×	×	**3.8%**
Cadmium	1.5%	×	0.03%	×	**1.5%**
Nickel	×	0.7%	0.2%	0.5%	**1.5%**
Molybdenum	×	1.0%	0.4%	0.02%	**1.4%**
Vanadium	×	×	0.01%	1.3%	**1.3%**
Niobium	×	×	0.04%	1.2%	**1.2%**
Selenium	0.8%	×	×	×	**0.8%**

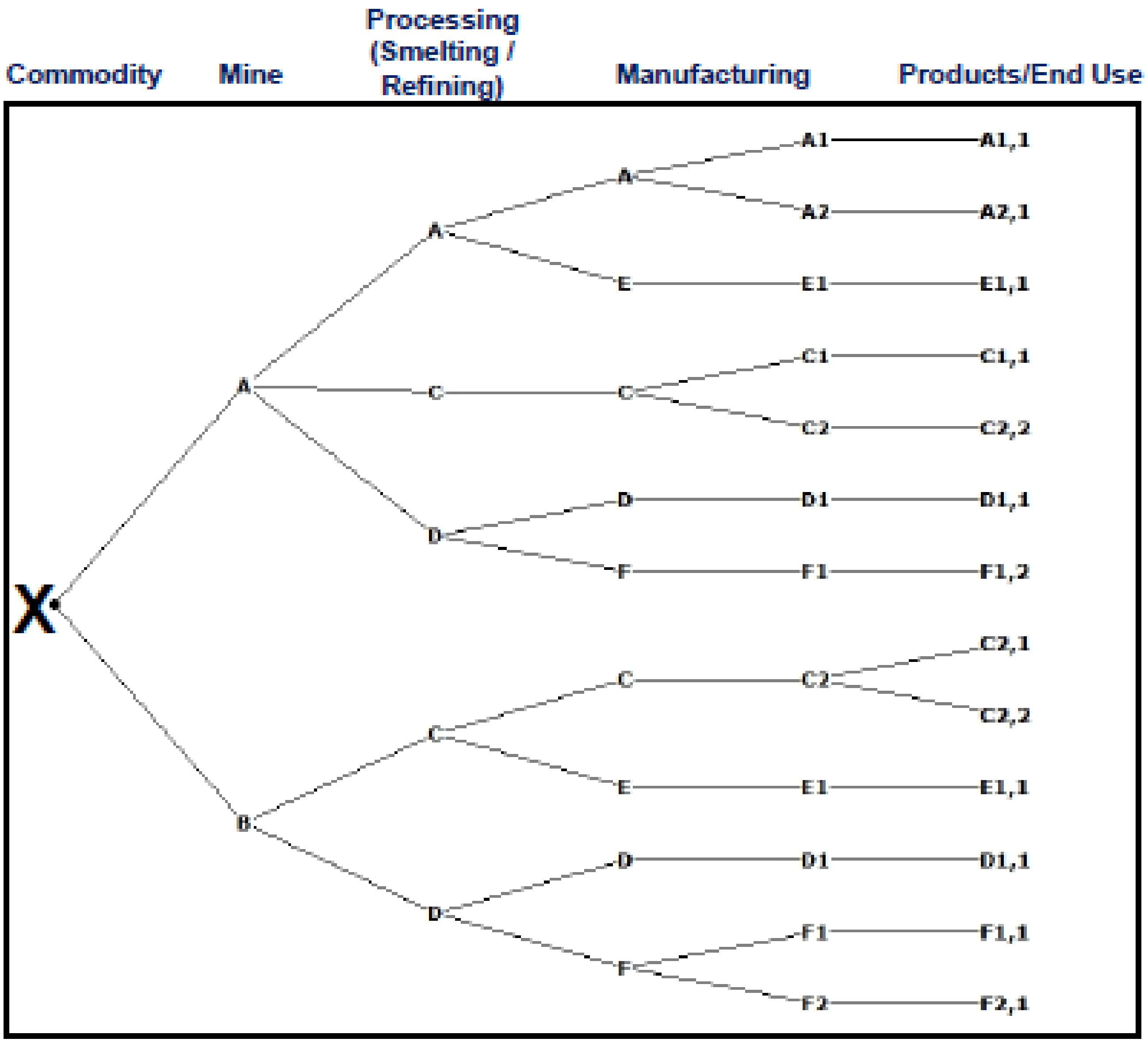
None for bioenergy and electricity grid

The US is 80% dependent for supply of 31 minerals.

This dependency implies criticality.



Supply Chain Analysis



<u>Example</u>

- Two sources of the commodity X (A,B)
- Three facilities that can process the raw material (A,C,D)
- 4 manufactured goods: (1,1), (1,2), (2,1), and (2,2)
- Good (1,1) is produced by 7 supply chains
- Good (1,2) is produced by only one supply chain
- Each supply chain can be disrupted in multiple places
- There are multiple probabilities of disruption that must be considered, based upon both natural and man-made events

What defines a supply disruption?

USGS

EMERGING TECHNOLOGIES

Cell phones

FACT SHEET | CELL PHONE

What's in my Cell Phone?

- **Arsenic (gallium arsenide in the amplifier and receiver).** Mined in China, Chile, Morocco, Peru, Kazakhstan, Russia, Belgium and Mexico.
- **Copper (circuitry).** Mined in Chile, United States, Peru, China, Australia, Russia, Indonesia, Canada, Zambia, Poland, Kazakhstan and Mexico.
- **Gallium (gallium arsenide).** Mined in China, Germany, Kazakhstan and Ukraine.
- **Gold (circuitry).** Mined in China, United States, Australia, South Africa, Peru, Russia, Canada, Uzbekistan, Ghana, Papua New Guinea, Indonesia, Brazil, Mexico and Chile.
- **Magnesium compounds (phone case).** Mined in China, Turkey, North Korea, Russia, Slovakia, Austria, Spain, Australia, Brazil, Greece, India and the United States.
- **Palladium (circuitry).** Mined in Russia, South Africa, Canada, United States and Zimbabwe.
- **Platinum (circuitry).** Mined in South Africa, Russia, Canada, Zimbabwe, United States and Colombia.
- **Silver (circuitry).** Mined in Peru, Mexico, China, Australia, Chile, Russia, United States, Poland, Bolivia and Canada.
- **Tungsten (circuitry).** Mined in China, Russia, Canada, Austria, Bolivia and Portugal.
- A multitude of **petroleum products** are used in cellular phones.

INTERESTING FACTS

- About 130 million cell phones are retired annually in the United States. Collectively, these cell phones weigh about 14,000 metric tons. Annually retired cell phones contain almost 2,100 metric tons of copper, 46 metric tons of silver, 3.9 metric tons of gold, 2 metric tons of palladium, and 0.04 metric tons of platinum.
- Recovery and recycling of cell phones are in the early stages of development, as is the case for recycling of electronics in general. For cell phone recycling to grow, recycling must become economically viable. Efficient recovery infrastructure, product designs that simplify dismantling, and other changes are needed to facilitate the growth of cell phone recycling.
- Gallium arsenide is used in the amplifier and receiver.
- Magnesium compounds are alloyed to make the cell phone cases.

Mineral Information Institute
an Affiliate of the SME Foundation
8307 Shaffer Parkway
Littleton, CO 80127
303-948-4200

www.mii.org | SME www.smenet.org

- **Cell phone performance dependence on a wide variety of minerals**
  - Scarce or expensive to process
  - **Barium titanate ceramics:** dielectric properties to avoid signal broadening and heat buildup
  - **Rare earth elements** (REs) and **indium:** ceramic magnetic switches
  - **Titanium dioxide:** dielectric heart of the phone
  - **Indium tin oxide:** liquid crystal display
  - **Tantalum:** dielectric resonators in 2.2 gigahertz cellular base stations
- **Markets for specialized minerals or mineral products in cell phone are small**
  - Volume of material needed for cell phones is small
  - Increased demand means sharp prices rises
    - **Indium:** 300$/kg late 90`s to 1000$/kg today

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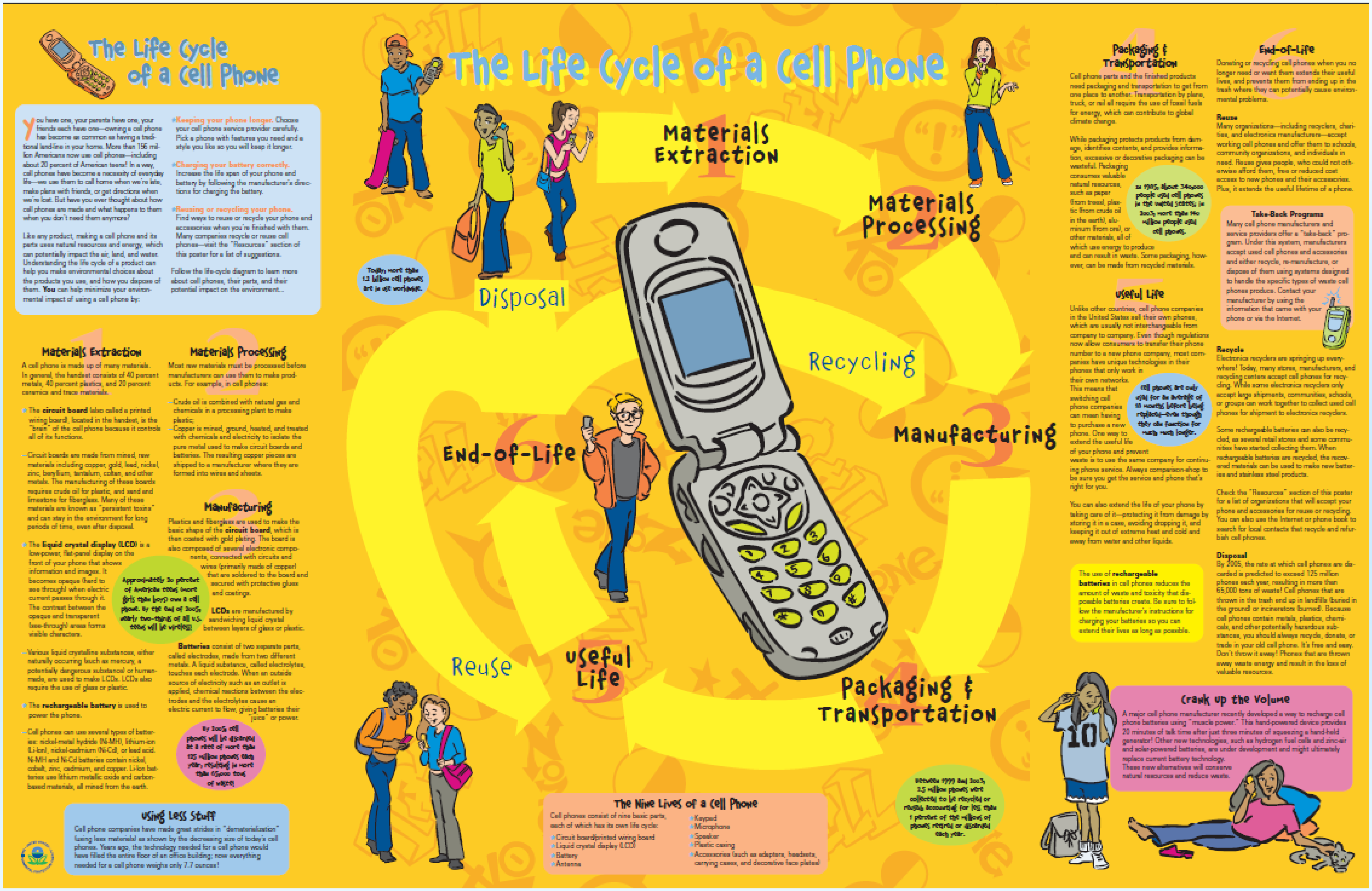
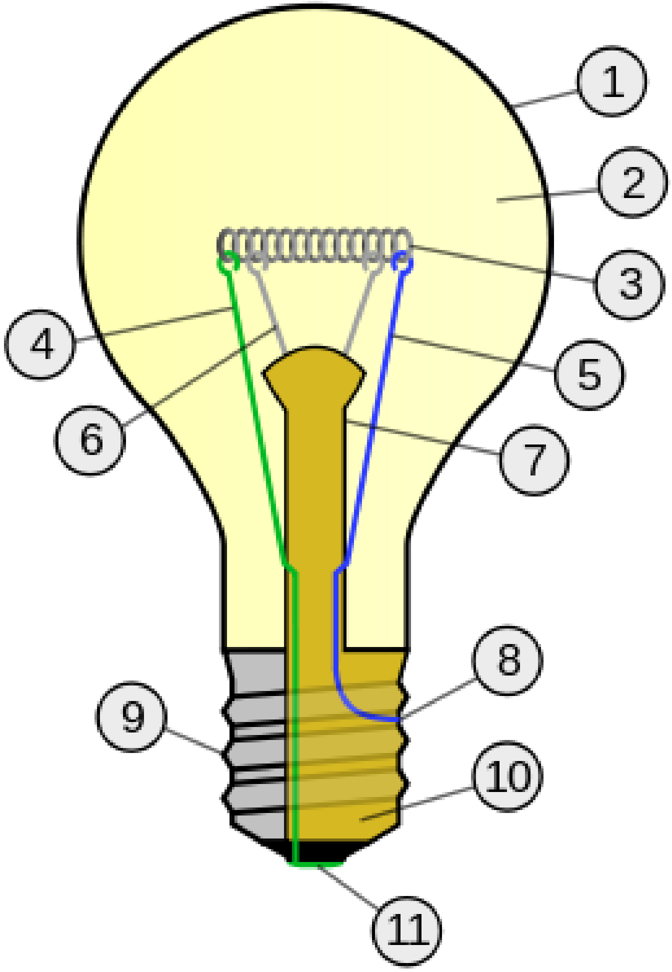


http://www.epa.gov/osw/education/pdfs/life-cell.pdf

LIGHT BULBS



1. Outline of Glass bulb
2. Low pressure inert gas (argon, nitrogen, krypton, xenon)
3. Tungsten filament
4. Contact wire (goes out of stem)
5. Contact wire (goes into stem)
6. Support wires (one end embedded in stem; conduct no current)
7. Stem (glass mount)
8. Contact wire (goes out of stem)
9. Cap (sleeve)
10. Insulation (vitrite)
11. Electrical contact

FACT SHEET **CFL Bulbs**

What's in a Compact Fluorescent Light Bulb?

- **Barite (for phosphor).** Mined in China, India, United States, Morocco, Iran, Turkey, Mexico, Kazakhstan, Vietnam, Germany, Russia, Algeria, United Kingdom and Pakistan.
- **Bauxite (alumina for phosphor; aluminum for end caps & filaments).** Mined in Australia, China, Brazil, India, Guinea, Jamaica, Russia, Venezuela, Suriname, Kazakhstan, Guyana and Greece.
- **Copper (end caps; filaments).** Mined in Chile, United States, Peru, China, Australia, Russia, Indonesia, Canada, Zambia, Poland and Mexico.
- **Lead (soda-lime glass; ballast; adapter unit).** Mined in China, Australia, United States, Peru, Mexico, Canada, India, Bolivia, Poland, Russia, Sweden, Ireland and South Africa.
- **Limestone or Dolomite (finely-crushed stone to make soda-lime glass).** Mined in United States.
- **Mercury (vapor in glass tubing).** Mined in China, Kyrgyzstan and Peru.
- **Nickel (end caps; filaments).** Mined in Russia, Canada, Australia, Indonesia, New Caledonia, Philippines, Columbia, China, Cuba, Brazil, Botswana, South Africa, Dominican Republic, Greece, Venezuela and Spain.
- **Phosphate Rock (phosphor).** Mined in China, United States, Morocco & Western Sahara, Russia, Tunisia, Jordan, Brazil, Syria, Israel, Egypt, Australia, South Africa and Canada.
- **Rare Earth Oxides (Lanthanum or Yttrium for phosphor).** Mined in China, India and Brazil.
- **Silica (glass).** Mined in United States, Italy, Germany, United Kingdom, Australia, France, Spain, Japan, Poland, Hungary, South Africa, Mexico, Austria, Iran, Republic of Korea, Slovakia, Canada, Belgium, India, Bulgaria, Norway, Chile, Gambia, Turkey and Czech Republic.
- **Soda Ash (soda-lime glass).** Mined in United States, Kenya and Botswana.
- **Manganese (phosphor).** Mined in South Africa, Australia, China, Gabon, Brazil, India, Ukraine and Mexico.
- **Tin (end caps; filaments; glass coatings).** Mined in China, Indonesia, Peru, Bolivia, Brazil, Congo-Kinshasa, Vietnam, Malaysia, Australia and Russia.
- **Tungsten (electrodes; filaments).** Mined in China, Russia, Canada, Austria, Bolivia and Portugal.
- **Zinc (end caps; filaments).** Mined in China, Peru, Australia, United States, Canada, India, Kazakhstan, Ireland and Mexico.

To learn more about minerals and mining visit
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INTERESTING FACTS

- CFLs are known as *compact fluorescent lights or compact fluorescent light bulbs.* In a CFL, an electric current is driven through a glass tube containing argon and a small amount of mercury vapor. This generates invisible ultraviolet light that excites a fluorescent coating (called phosphor) on the inside of the tube, which then emits visible light.
- CFLs are made of soda-lime glass, similar to that used throughout the glass industry for bottles and other common products.
- Phosphor in a CFL is a phosphate mix that may contain manganese, rare elements such as lanthanum, and yttrium as either an oxide or a phosphate, along with a barium/aluminum oxide. Phosphor components may vary slightly depending on the color of the lamp.
- While a regular (incandescent) light bulb uses heat to produce light, a fluorescent bulb creates light using an entirely different method that is 4 to 6 times more energy-efficient. This means that a 15-watt CFL produces the same amount of light as a 60-watt regular incandescent bulb. CFLs last up to 13 times longer and use 2/3 to 3/4 less electricity than incandescent bulbs with similar lumen ratings.
- CFLs contain a very small amount of mercury sealed within the glass tubing – an average of 4 milligrams. By comparison, older thermometers contain about 500 milligrams of mercury – an amount equal to the mercury in 125 CFLs. Mercury is an essential part of CFLs; it allows the bulb to be an efficient light source. No mercury is released when the bulbs are intact (not broken) or in use. Because the CFLs contain mercury, the U.S. Environmental Protection Agency encourages their recycling after they burn out. In some states, CFL recycling may be mandatory.
- China supplies 97% of the world's supply of rare earths, which are used in a variety of products.
- The U.S. possesses the largest non-China rare earth resource in the world at the Mountain Pass Mine in California.

CD/DVD

FACT SHEET CDs & DVDs

What's That Disc Made Of?

- **Bauxite (aluminum):** Mined in Australia, China, Brazil, India, Guinea, Jamaica, Russia, Venezuela, Suriname, Kazakhstan, Guyana and Greece.
- **Gold (reflects laser beam):** Mined in China, United States, Australia, South Africa, Peru, Russia, Canada, Uzbekistan, Ghana, Papua New Guinea, Indonesia, Brazil, Mexico and Chile.
- **Oil, Oil Sands or Oil Shale (polycarbonate plastic):** From oil drilling, mined oil sands, or oil shale.

INTERESTING FACTS

- The discs are made of plastics and metals. The largest ingredient is polycarbonate plastic derived from oil. Can be processed from oil drilling or mined from oil sand or oil shale.
- The most important part of the disc is the thin metal layer that reflects laser beams used to read the information on the disc.
- Most discs are thrown into landfills because people are not aware that they can be recycled. *Goodwill, Salvation Army* and *Best Buy* recycle CDs and DVDs. *Back Thru the Future, CD Recycling Center of America* and *Green Disk* are located online and offer many tips on how to recycle CDs and DVDs.

SOURCES

http://minerals.usgs.gov/minerals/pubs/mcs/
www.mediatechnics.com/dvdcopiers.htm
www.all4dvd.com/images/dvd_discs.png
www.mediatechnics.com/dvdcopiers.htm
www.earth911.com
www.cdrecyclingcenterofamerica.com
www.kodak.com

Researcher: Ben Larson,
Colorado School of Mines

Edited by the U.S. Geological Survey 2010

To learn more about minerals and mining visit
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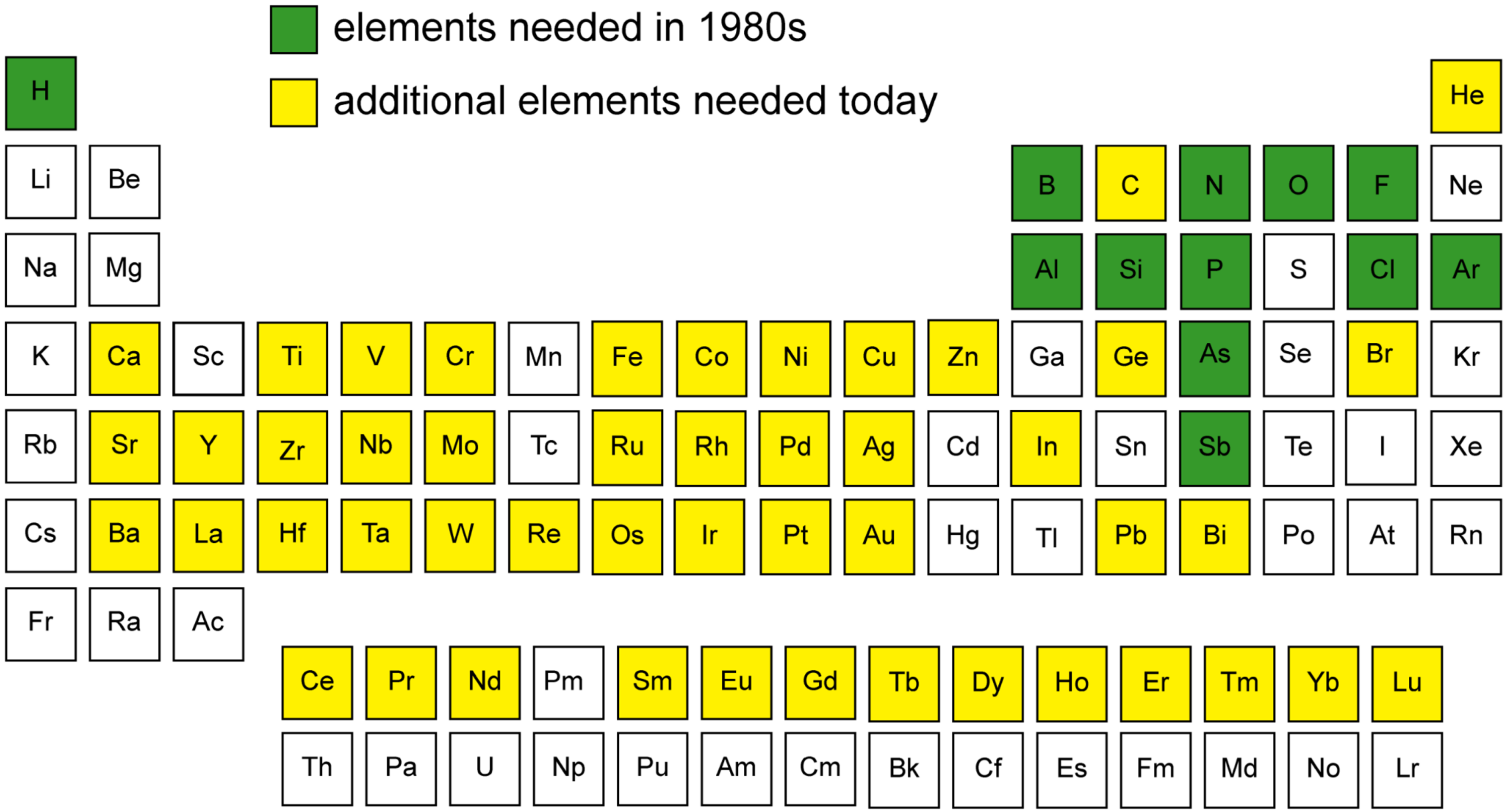
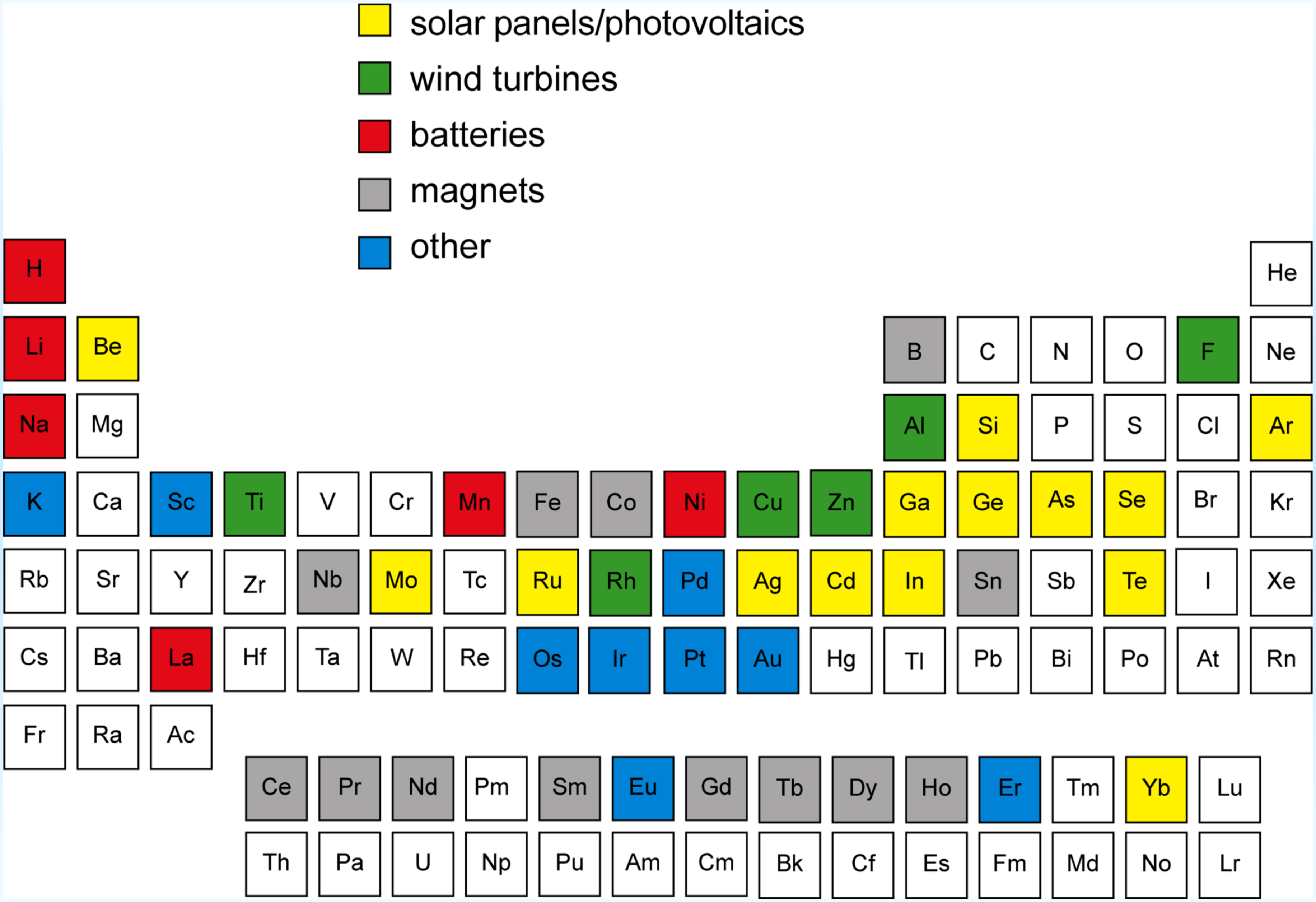
Elements in Computer Chips
(National Research Council, 2007)



What are green technologies?

- Environmental technologies or clean technologies
- Future and existing technologies that conserve energy and natural resources and curb the negative impacts of human involvement, i.e. environmental friendly (modified from Wikipedia)
  - Alternative power (wind turbines, solar energy)
  - Hybrid and electric cars
  - Batteries
  - Magnets
- Other technologies
  - Water purification
  - Desalination
  - Carbon capture and storage


solar panels/photovoltaics
wind turbines
batteries
magnets
other
H He
Li Be B C N O F Ne
Na Mg Al Si P S Cl Ar
K Ca Sc Ti V Cr Mn Fe Co Ni Cu Zn Ga Ge As Se Br Kr
Rb Sr Y Zr Nb Mo Tc Ru Rh Pd Ag Cd In Sn Sb Te I Xe
Cs Ba La Hf Ta W Re Os Ir Pt Au Hg Tl Pb Bi Po At Rn
Fr Ra Ac
Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
Th Pa U Np Pu Am Cm Bk Cf Es Fm Md No Lr

Common minerals

- Cement/concrete
- Copper
- Steel
- Aluminum
- Titanium

AUTOMOBILES

TABLE 2.2 Some Minerals and Their Weights and Properties in Today's Automobile

Mineral	2006 Weight (pounds/kilograms)	Property
Iron & Steel	2124/ 963	High strength, durability (frame, motor)
Aluminum	240/109	Light weight (frame, motor)
Carbon	50/23	Bond strengthener (tires and other rubber parts)
Copper	42/19	Electrical conductivity
Silicon	41/19	Bonding properties (windshields and windows)
Lead	24/11	Conductor (storage batteries)
Zinc	22/10	Galvanizer, strengthens in metal alloys (die cast parts and galvanized metal)
Manganese	17/8	Hardens as metal alloy
Chromium	15/7	Corrosion resistance and hardness as metal alloy
Nickel	9/4	Strength at elevated temperature and corrosion resistance as metal alloy
Magnesium	4.5/2	Alloying element with other metals like aluminum
Sulfur	2/0.9	Strengthens rubber tires
Molybdenum	1/4.5	Strength and toughness as metal alloy
Vanadium	<1/<0.45	Strengthens, hardens, lighter weight as metal alloy
Platinum	0.05-0.10 troy ounce/ 1.5 – 3.0 grams	Catalytic properties (catalytic converters)

http://www.nma.org/pdf/101606_nrc_study.pdf

Table 2-1. Materials in Clean Energy Technologies and Components

		CLEAN ENERGY TECHNOLOGIES AND *COMPONENTS*				
		Solar Cells	Wind Turbines	Vehicles		Lighting
	MATERIAL	*PV films*	*Magnets*	*Magnets*	*Batteries*	*Phosphors*
Rare Earth Elements	Lanthanum				●	●
	Cerium				●	●
	Praseodymium		●	●	●	
	Neodymium		●	●	●	
	Samarium		●	●		
	Europium					●
	Terbium					●
	Dysprosium		●	●		
	Yttrium					●
	Indium	●				
	Gallium	●				
	Tellurium	●				
	Cobalt				●	
	Lithium				●	

Toyota Prius

2.2 lbs Nd in magnets

22-33 lbs La in batteries

http://www.molycorp.com/hybrid_ev.asp

BATTERIES

Batteries

- Primary (immediate current, disposable) vs secondary (must be charged)
- Types
  - Wet cell
  - Dry cell
  - Molten salt
  - reserve
- Dependent upon use
  - Computers, cell phones
  - Solar power system

Significant Growth in Portable Lithium-Ion

Batteries

→ Mobile Electronics

WESTERN LITHIUM WLC

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		CLEAN ENERGY TECHNOLOGIES AND *COMPONENTS*				
		Solar Cells	Wind Turbines	Vehicles		Lighting
	MATERIAL	*PV films*	*Magnets*	*Magnets*	*Batteries*	*Phosphors*
Rare Earth Elements	Lanthanum				●	●
	Cerium				●	●
	Praseodymium		●	●	●	
	Neodymium		●	●	●	
	Samarium		●	●		
	Europium					●
	Terbium					●
	Dysprosium		●	●		
	Yttrium					●
	Indium	●				
	Gallium	●				
	Tellurium	●				
	Cobalt				●	
	Lithium				●	

Other materials

- Zinc
- Carbon
- Chloride
- Manganese
- Nickel
- Lithium
- Copper
- Silver
- Cadmium
- Lead
- REE
- Iron
- mercury

PHOTOVOLTAICS

FACT SHEET SOLAR PANELS

Metals & Mineral Products used to make a Solar Panel

- **Arsenic (gallium-arsenide semiconductor chips)**. Mined in China, Chile, Morocco, Peru, Kazakhstan, Russia, Belgium and Mexico.
- **Bauxite (aluminum)**. Mined in Australia, China, Brazil, India, Guinea, Jamaica, Russia, Venezuela, Suriname, Kazakhstan, Guyana and Greece.
- **Boron Minerals (semiconductor chips): Mined in United States, Turkey, Argentina, Chile, Russia, Peru, China, Bolivia and Kazakhstan.**
- **Cadmium (thin film solar cells)**. Mined in China, Republic of Korea, Japan, Kazakhstan, Mexico, Canada, Russia, United States, India, Netherlands, Poland, Germany and Australia.
- **Coal (by-product coke is used to make steel)**. Coal is mined world-wide, and constitutes 45% of the generation of U.S. electricity.
- **Copper (wiring; thin film solar cells): Mined in Chile, United States, Peru, China, Australia, Russia, Indonesia, Canada, Zambia, Poland and Mexico.**
- **Gallium (solar cells)**. Mined in China, Germany, Kazakhstan and Ukraine.
- **Indium (solar cells)**. Mined in China, Republic of Korea, Japan, Canada, Belgium, Russia, Peru and Brazil.
- **Iron ore (steel)**. Mined in China, Brazil, Australia, India, Russia, Ukraine, United States, South Africa, Iran, Canada, Sweden, Kazakhstan, Venezuela and Mexico.
- **Molybdenum (photovoltaic cells). Mined in China, United States, Chile, Peru, Mexico, Canada, Armenia, Iran, Russia and Mongolia.**
- **Lead (batteries)**. Mined in China, Australia, United States, Peru, Mexico, Canada, India, Bolivia, Poland, Russia, Sweden, Ireland and South Africa.
- **Phosphate rock (phosphorous)**. Mined in China, United States, Morocco, Western Sahara, Russia, Tunisia, Jordan, Brazil, Syria, Israel, Egypt, South Africa and Canada.
- **Selenium (solar cells)**. Mined in Japan, Belgium, Canada, Russia, Chile, the Philippines, Finland, Peru, Sweden and India.
- **Silica (solar cells)**. Mined in United States, Italy, Germany, United Kingdom, Australia, France, Spain, Japan, Poland, Hungary, South Africa, Mexico, Austria, Iran, Republic of Korea, Slovakia, Canada, Belgium, India, Bulgaria, Norway, Chile, Gambia, Turkey and Czech Republic.
- **Tellurium (solar cells)**. Mined in Australia, Belgium, Canada, China, Germany, Japan, Kazakhstan, Peru, Philippines, Russia and United States.
- **Titanium dioxide (solar panels)**. Mined in Australia, South Africa, Canada, China, India, Norway, Ukraine, Vietnam, Mozambique, United States, Sierra Leone and Brazil.

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SME Society for Mining, Metallurgy & Exploration

INTERESTING FACTS

In 1954 Photovoltaic technology was born in the United States when Daryl Chapin, Calvin Fuller, and Gerald Pearson develop the silicon photovoltaic (PV) cell at Bell Labs—the first solar cell capable of converting enough of the sun's energy into power to run everyday electrical equipment.

Molybdenum is "sputtered" onto the photovoltaic cells as a base conductive layer for all the other layers. Sputtering is a process that uses ions of an inert gas to dislodge atoms from the surface of a crystalline material, the atoms then being electrically deposited to form an extremely thin coating on a glass, metal, plastic, or other surface.

Photovoltaics

- Specialty
  - Commercial
    - Silicon
    - Silver
    - **Tellurium**
    - Cadmium
  - Emerging
    - **Indium**
    - **Selenium**
    - Molybdenum
    - **Gallium**
    - Germanium
    - Arsenic
    - Ruthenium
  - Many minor materials (Ni, P, Zn, Sn, S, N, H, more)
- Bulk
  - Steel
  - Aluminum
  - **Copper**
  - Adhesive
  - Insulating
  - Concrete
  - Plastic

Ken Zweibel, GW Solar Institute, “Minerals for a Green Society”, Metallurgical Society of America, Feb 4, 2010

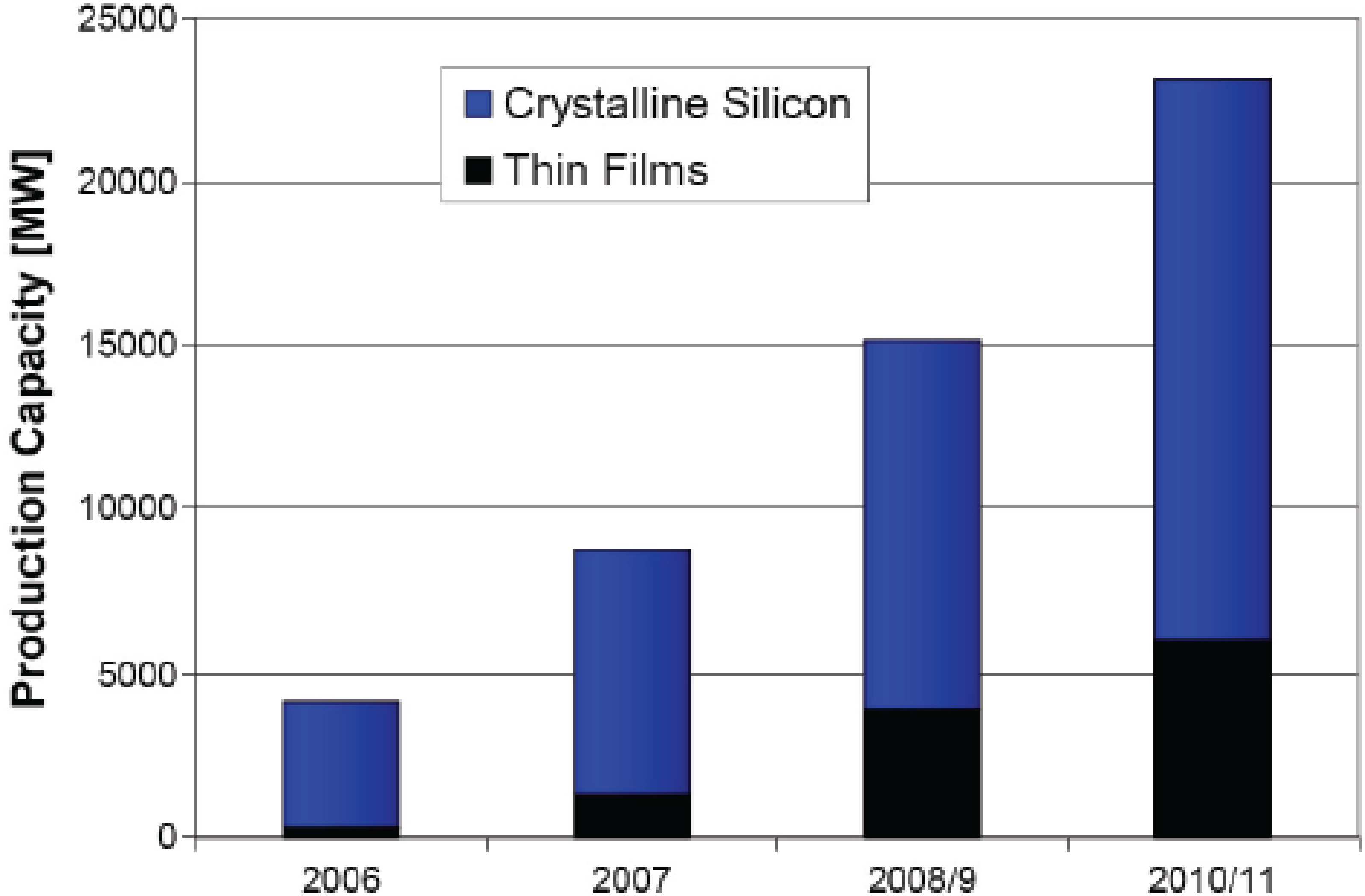


Figure 6.3: PV Production Capacities 2006 and forecast (Source: Jäger-Waldau 2007)

Figure 6.3 shows the actual and planned production capacities for the worldwide photovoltaic industry. Clearly visible is the growing use of thin film cells in the PV industry. It must be

Photovoltaics

Approximate Amounts (2010)

	Thickness (microns), g/m2 (90% use)	g/W	Cost ($/g, $/W, $/m2; bulk, pure)	Competing Uses	Concern (mid- & long-term)
Te	3 um; 10-12 g	0.1 g/W (@ 110 W/m2)	$0.3/g, $0.03/W, $3.3/m2	Few and small	Price & Supply, and Intrinsic Availability
In	1-2 um; 2-4 g (In/Ga = 4)	0.02-0.04 g/W (@ 110 W/m2)	$0.5/g, $0.02/W, $1.5/m2	LCD (large and valuable)	Price & Supply, and Intrinsic Availability
Ga	1-2 um; 0.5-1 g (In/Ga =4)	0.005-0.01 g/W (@ 110 W/m2)	$0.5/g, $0.005/W, $0.4/m2	Few and small	Price & Supply, and Intrinsic Availability
Mo	1 um; 10 g	0.1 g/W (@ 110 W/m2)	$0.02/g, $0.002/W, $0.2/m2	Large	Price
Se	1-2 um; 3.5-7 g/m2	0.03-0.06 g/W (@ 110 W/m2)	$0.1/g, $0.005/W, $0.5/m2	Large and valuable	Price & Supply, and Intrinsic Availability
Ag	30 g/m2	0.2 g/W (@ 160 W/m2)	$0.5/g, 0.09/W, $15/m2	Large and valuable	Price
Cu				Large and valuable	Price

Ken Zweibel, GW Solar Institute, “Minerals for a Green Society”, Metallurgical Society of America, Feb 4, 2010

Photovoltaics

Approximate Future (2030) Amounts

	Thickness (microns), g/m2 (90% use)	g/W	Cost ($/g, $/W, $/m2; bulk, pure feedstock), 2010 prices	Competing Uses	How?
Te	2/3 um; 2 g	0.013 g/W (@ 150 W/m2)	$0.5/g, $0.007/W, $1/m2	Few and small	Thinner CdTe, Higher Efficiency
In	0.75 um; 1.5 g (In/Ga = 4)	0.01 g/W (@ 160 W/m2)	$1/g, $0.01/W, $1.5/m2	LCD (large and valuable)	Thinner CuInSe2 Alloy, Higher Efficiency
Ga for CIS	0.75 um; 0.4 g (In/Ga =4)	0.0025 g/W (@ 160 W/m2)	$1/g, $0.0025/W, $0.4/m2	Few and small	Thinner CuInSe2 Alloy, Higher Efficiency
Mo	0.5 um; 5 g	0.03 g/W (@ 160 W/m2)	$0.02/g, $0.0006/W, $0.1/m2	Large	Thinner Mo contact, Higher Efficiency
Se	0.75 um; 2.6 g/m2	0.016 g/W (@ 160 W/m2)	$0.2/g, $0.003/W, $0.5/m2	Large and valuable	Thinner CuInSe2 Alloy, Higher Efficiency
Ag	15 g/m2	0.07 g/W (@ 220 W/m2)	$1/g, 0.1/W, $15/m2	Large and valuable	Higher Efficiency
Cu				Large and valuable	

Ken Zweibel, GW Solar Institute, “Minerals for a Green Society”, Metallurgical Society of America, Feb 4, 2010

Indium in solar panels

- 50 metric tons required for enough solar panels to provide 1 gigawatt of energy
- $500/kg in 2009
- 2008—US used 800 megawatts of energy by solar panels connected to the grid (0.1% total US energy)
- 600,000 metric tons reserves in the world in 2009
  - – Zinc sulfide deposits
  - – Tin-tungsten veins
  - – Porphyry copper deposits

Ingots of Indium.

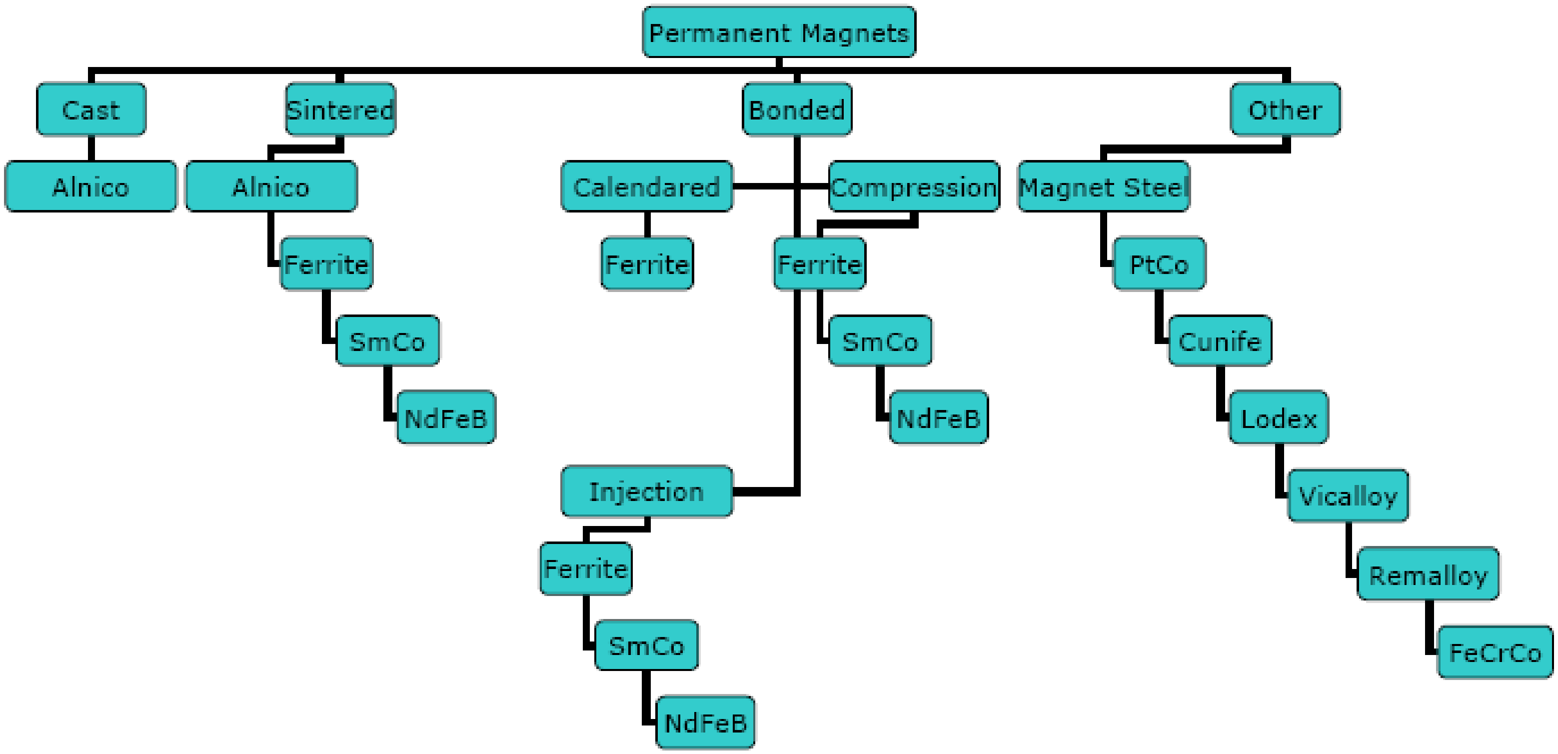
MAGNETS

Permanent Magnets

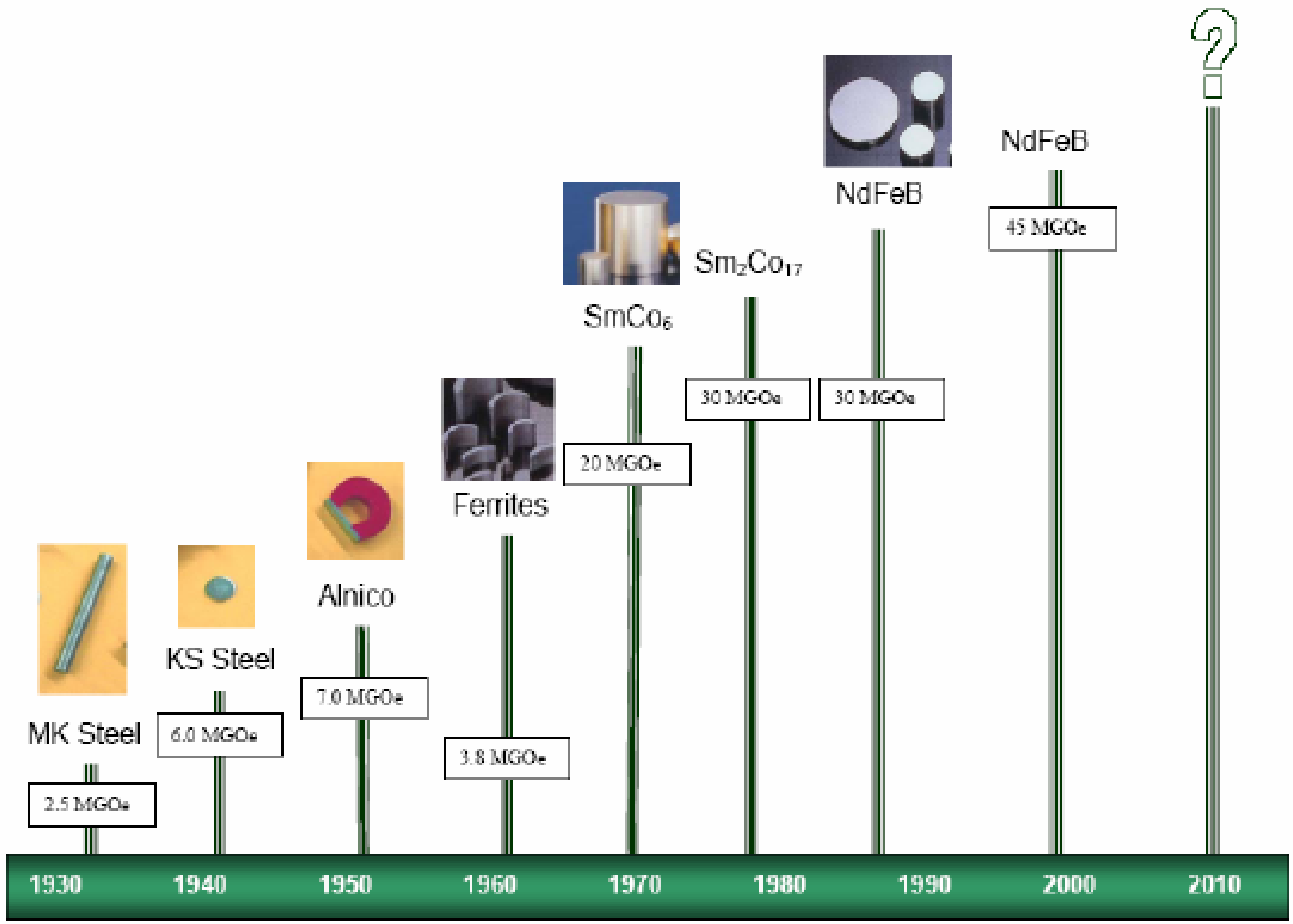
- Automotive
- Electronics
- Appliances
- Medical
- Military
- Aerospace
- Automation
- Wind turbines

- Fe
- Sm-Co
- Nd-Fe-B
- Cu-Ni-Fe
- Fe-Cr-Co
- Al-Ni-Co

The Magnet Family



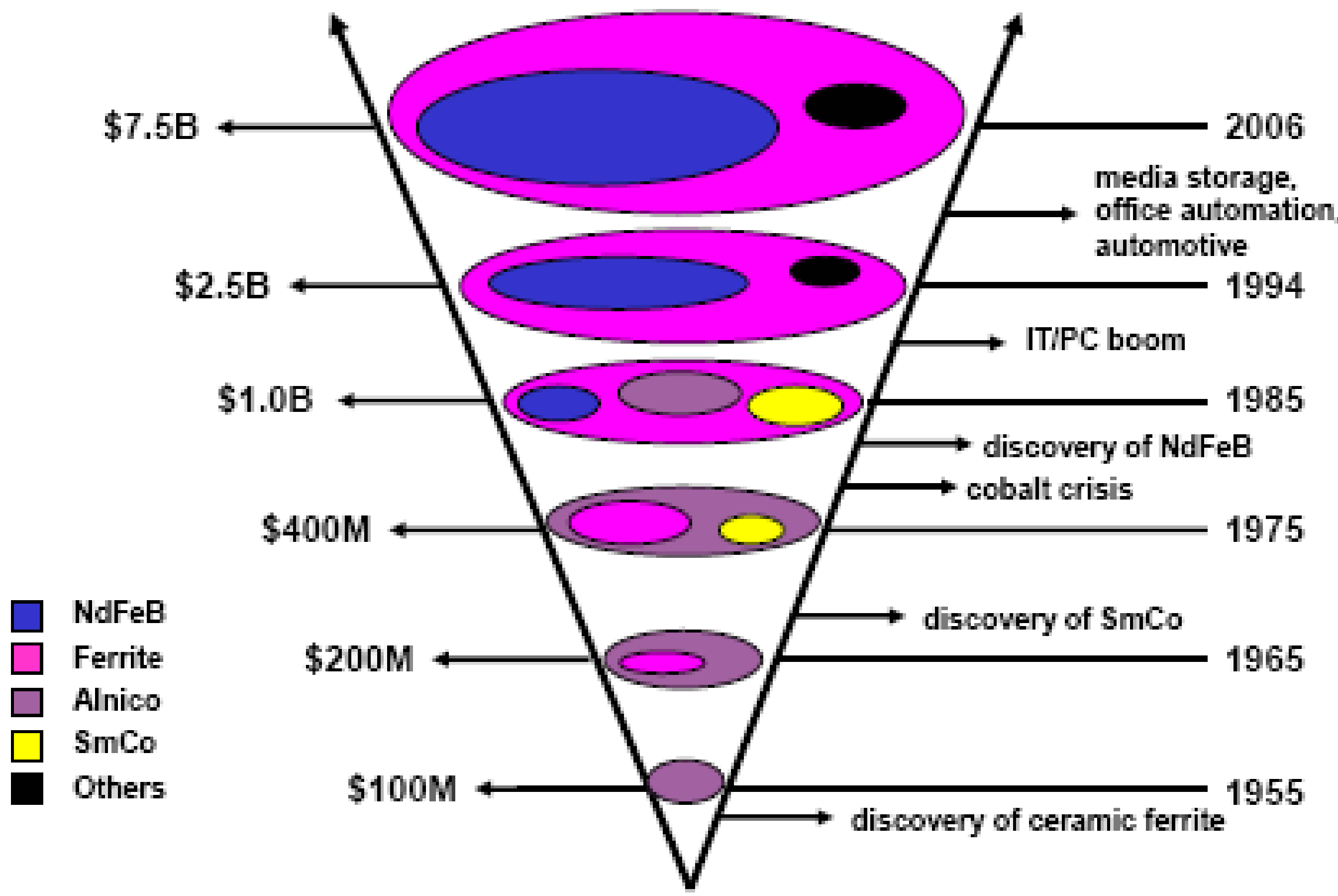
History of Magnetic Materials



Magnetweb.com

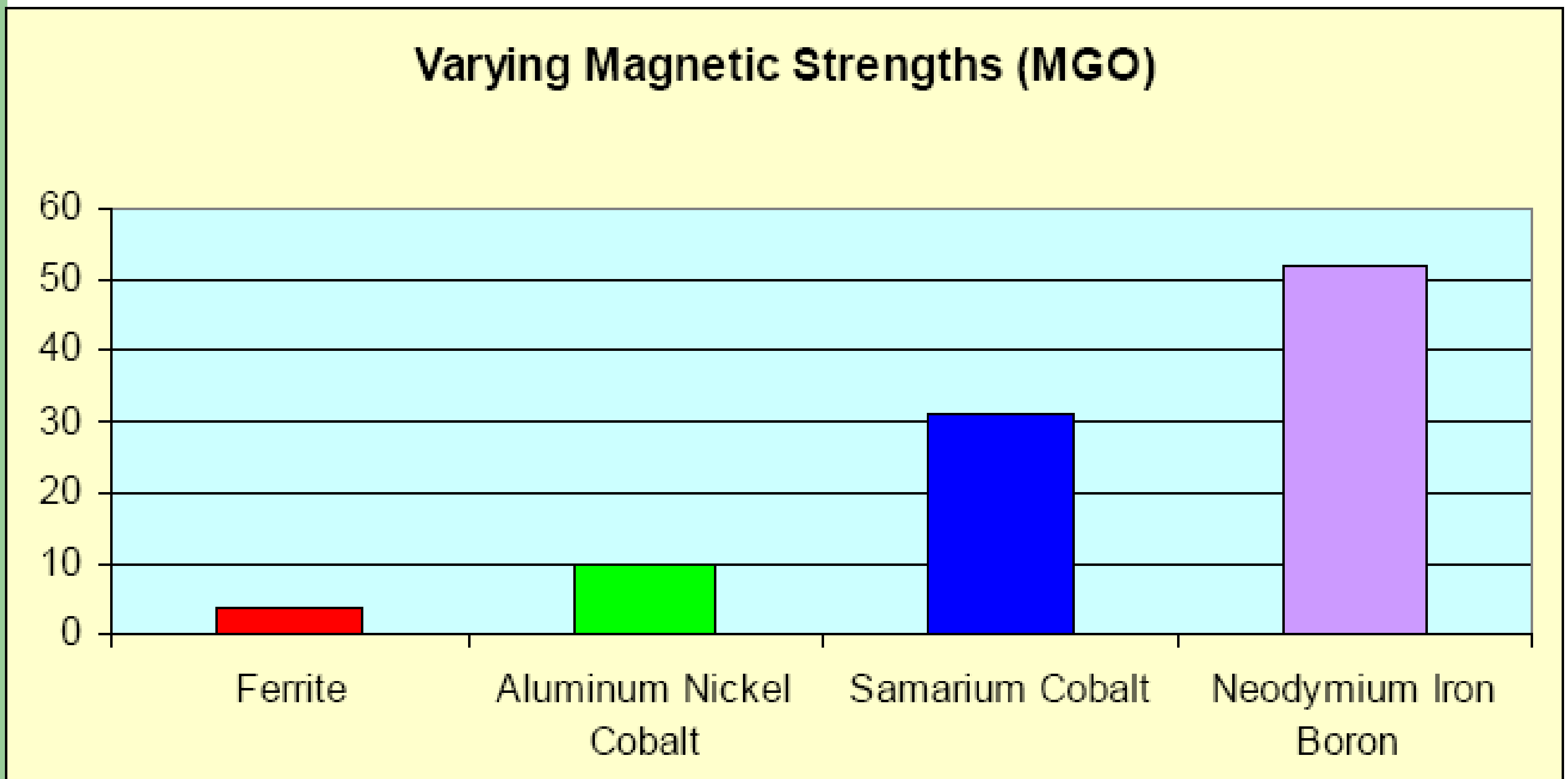
Innovative Magnet Applications

Global value growth of permanent magnets



2007 Magnetics Conference

Permanent Magnet Types & Strength



Rare earths

WIND TURBINES

FACT SHEET | WIND TURBINES

What Mineral Products & Metals Are Needed To Make Wind Turbines?

- **Aggregates and Crushed Stone (for concrete):** Mined in the United States.
- **Bauxite (aluminum):** Mined in Australia, China, Brazil, India, Guinea, Jamaica, Russia, Venezuela, Suriname, Kazakhstan, Guyana and Greece.
- **Clay and Shale (for cement):** Mined in United States.
- **Coal (by-product coke is used to make steel).** Coal is mined world-wide, and constitutes 45% of the generation of U.S. electricity.
- **Cobalt (magnets):** Mined in Congo-Kinshasa, Canada, Zambia, Russia, Australia, China, Cuba, Morocco, New Caledonia and Brazil.
- **Copper (wiring):** Mined in Chile, United States, Peru, China, Australia, Russia, Indonesia, Canada, Zambia, Poland and Mexico.
- **Gypsum (for cement):** Mined in China, United States, Iran, Spain, Thailand, Japan, Canada, Italy, France, Australia, Turkey, India, Russia, Saudi Arabia, Brazil, Egypt, Germany, United Kingdom, Algeria, Poland, Argentina and Austria.
- **Iron ore (steel):** Mined in China, Brazil, Australia, India, Russia, Ukraine, United States, South Africa, Iran, Canada, Sweden, Kazakhstan, Venezuela and Mexico.
- **Limestone (for cement):** Mined in United States.
- **Molybdenum (alloy in steel):** Mined in China, United States, Chile, Peru, Mexico, Canada, Armenia, Iran, Russia and Mongolia.
- **Rare Earth Oxides (magnets; batteries):** Mined in China, India and Brazil.
- **Zinc (galvanizing):** Mined in China, Peru, Australia, United States, Canada, India, Kazakhstan, Ireland and Mexico.
- **Silica Sand (for cement):** Mined in United States, Italy, Germany, United Kingdom, Australia, France, Spain, Japan, Poland, Hungary, South Africa, Mexico, Austria, Iran, Republic of Korea, Slovakia, Canada, Belgium, India, Bulgaria, Norway, Chile, Gambia, Turkey and Czech Republic.

INTERESTING FACTS

- The foundation may contain over a thousand tons of concrete and rebar. Dimensions are often between 30-50 ft. across and 6-30 ft. deep.
- The average tower height is 229 ft. 8 in. Shafts are sometimes driven down farther to help anchor it. The platform is critical to stabilizing the immense weight of the turbine assembly.
- Depending on the model, industrial wind turbines can weigh between 164-334 tons, or more.
- 5,000 commercial-scale wind turbines were installed in 2008.
- Like old fashioned windmills, today's wind turbines use blades to collect the kinetic energy of the wind. The wind flows over the blades creating lift, like the effect on airplane wings, which causes them to turn. The blades are connected to a drive shaft that turns an electric generator to produce electricity.
- When the wind isn't blowing, other types of power plants must be used to make electricity.
- Wind turbines also use neodymium, boron and iron magnets in their construction and operation.
- The U.S. possesses the largest non-China rare earth resource in the world at the Mt. Pass Mine in California.

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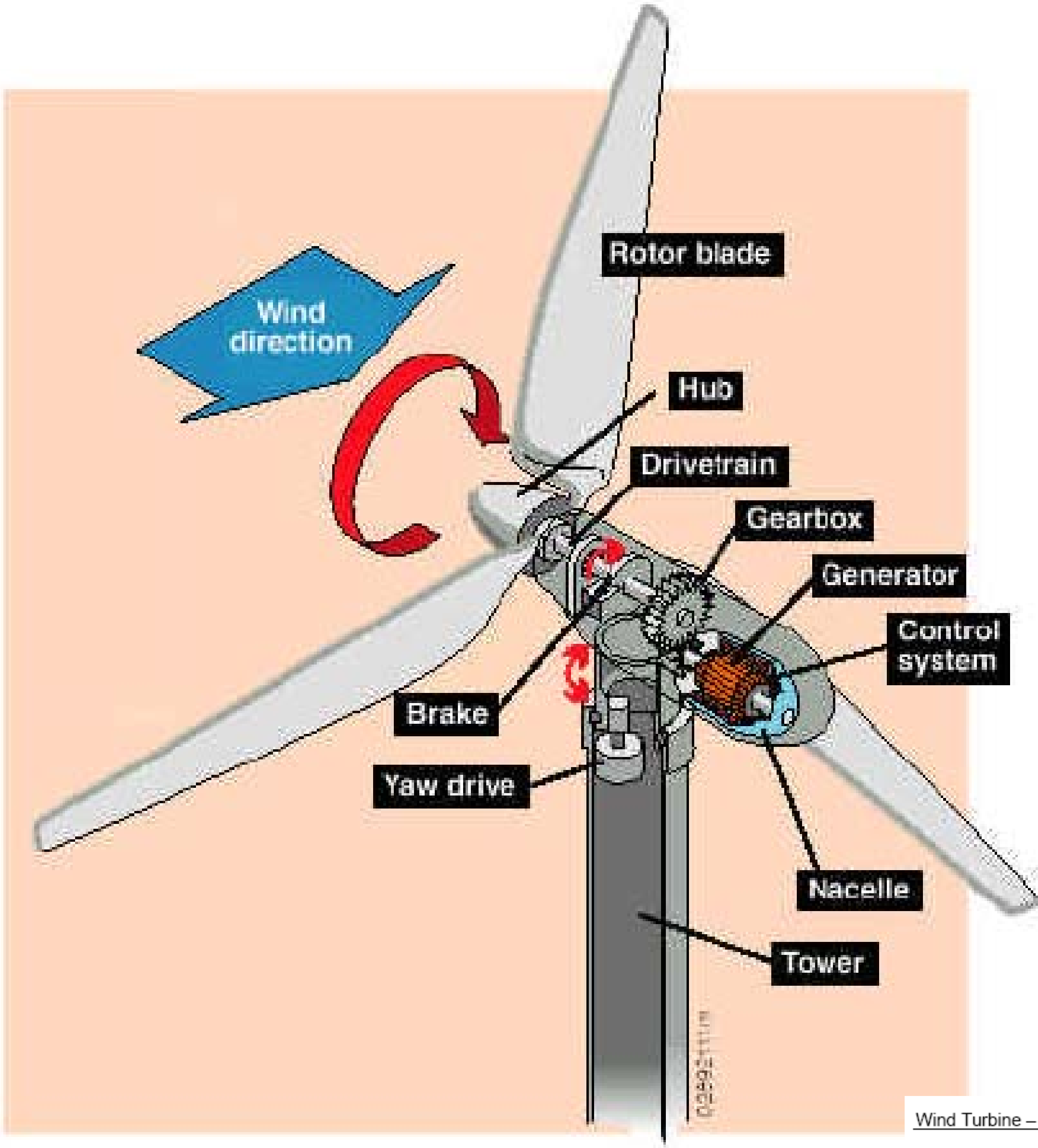
Wind turbines



Wind Turbine Nomenclature

Wind Turbine – Materials and Manufacturing Fact Sheet August 29, 2001

Wind Turbine - Materials and Manufacturing Fact Sheet

Prepared for the Office of Industrial Technologies, US Department of Energy
By Princeton Energy Resources International, LLC.
Dan Ancona and Jim McVeigh

Table 1. Turbine Component Weight and Cost

Component	% of Machine Weight	% of Machine Cost [5]
Rotor	10-14	20-30
Nacelle and machinery, less	25-40	25
Gearbox and drivetrain	5-15	10-15
Generator systems	2-6	5-15
Weight on Top of Tower	35-50	N/A
Tower	30-65	10-25

Table 3. Percentage of Materials Used in Current Wind Turbine Component

	Large Turbines and *(Small Turbines*[1]*)*								
Component/ Material (% by weight)	**Permanent Magnetic Materials**	**Pre-stressed Concrete**	**Steel**	**Aluminum**	**Copper**	**Glass Reinforced Plastic**[4]	**Wood Epoxy**[4]	**Carbon Filament Reinforced Plastic**[4]
Rotor								
Hub			*(95)* - 100	*(5)*				
Blades			5			95	*(95)*	*(95)*
Nacelle[2]	*(17)*		*(65)* - 80	3 - 4	14	1 - *(2)*		
Gearbox[3]			98 -*(100)*	*(0)* - 2	*(<1)* - 2			
Generator	*(50)*		*(20)* - 65		*(30)* - 35			
Frame, Machinery & Shell			85 - *(74)*	9 - *(50)*	4 - *(12)*	3 - *(5)*		
Tower		2	98	*(2)*				

Notes:
1. Small turbines with rated power less than 100 kW- (listed in italics where different)
2. Assumes nacelle is 1/3 gearbox, 1/3 generator and 1/3 frame & machinery
3. Approximately half of the small turbine market (measured in MW) is direct drive with no gearbox
4. Rotor blades are either glass reinforced plastic, wood-epoxy or injection molded plastic with carbon fibers

Wind Turbine - Materials and Manufacturing Fact Sheet

Prepared for the Office of Industrial Technologies, US Department of Energy
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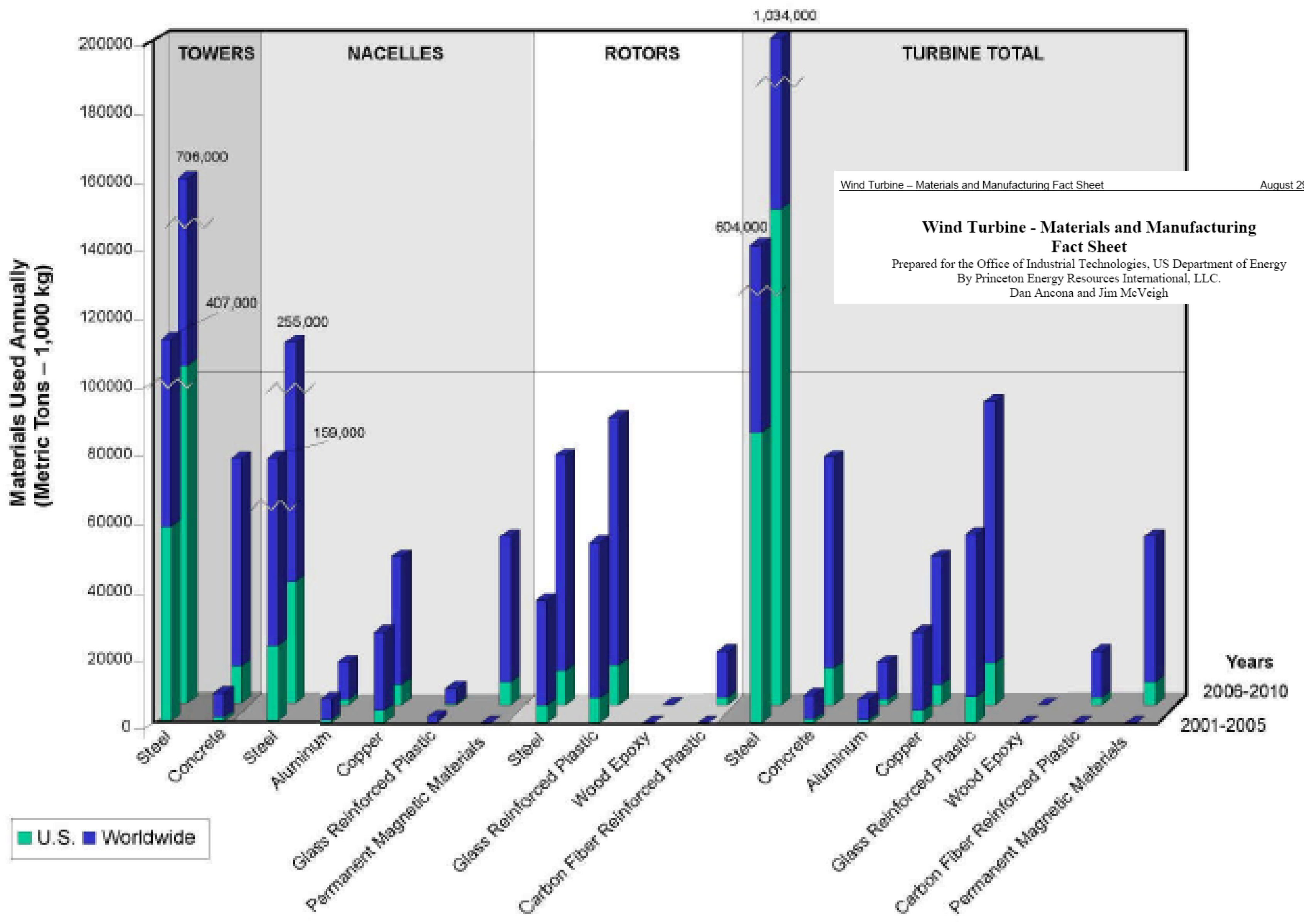
Wind Turbine Materials Usage



Wind Turbine – Materials and Manufacturing Fact Sheet August 29, 2001

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ENGINES

Minerals in Pratt & Whitney F100 Turbofan Engine

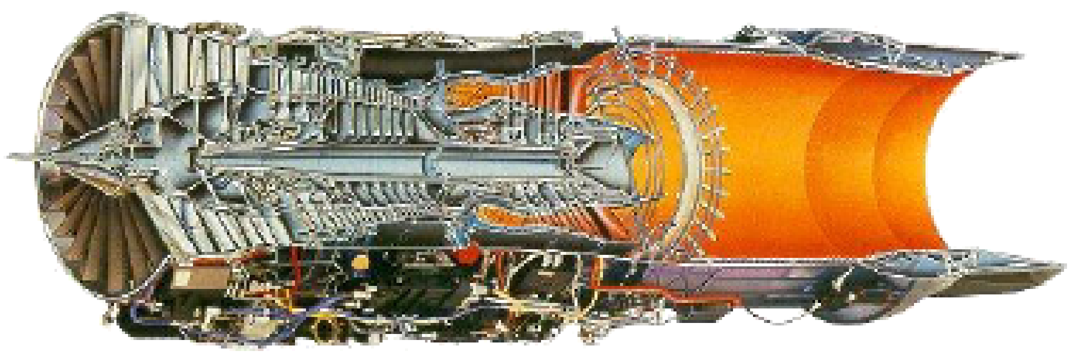
Center for Strategic Leadership CSL

Nickel
4,504 Lbs.

Titanium
5,440 Lbs.

Chromium
1,485 Lbs

F100-PW-229 TURBOFAN ENGINE



Columbium
145 Lbs.

Manganese
23 Lbs.

Cobalt
885 Lbs

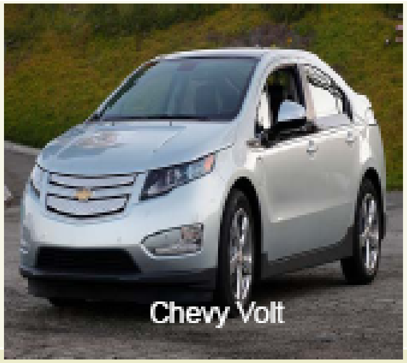
CHALLENGES

GENERAL COMMENTS

- Many of these minerals do not require the tonnages we are used to mine for metals like Fe, Cu, Pb, Zn—i.e. smaller deposits

Commodity	US production 2009 mt	World production 2009 mt	consumption 2009 mt	Price 2009	World reserves 2009 mt
Cu	1,190,000	15,800,000	1,660,000	$2.3/lb	540,000,000
Au	210	2,350	170	$950/oz	47,000
REO	0	124,000	7,410	varies	99,000,000
Be	120	140	140	$120/lb	15900+
Sb	0	187,000	22,400	$2.3/lb	2,100,000
As	385	52,500	3,600	$0.92/lb	1,070,000
Bi	100	7,300	1,020	$7.4/lb	320,000
Ga	0	78	20	$480/kg	1,000,000
Ge	5	14	5	$950/kg	450+
Te	W		W	$145/kg	22,000
cement	71,800,000	2,800,000,000	73,800,000	$100/mton	

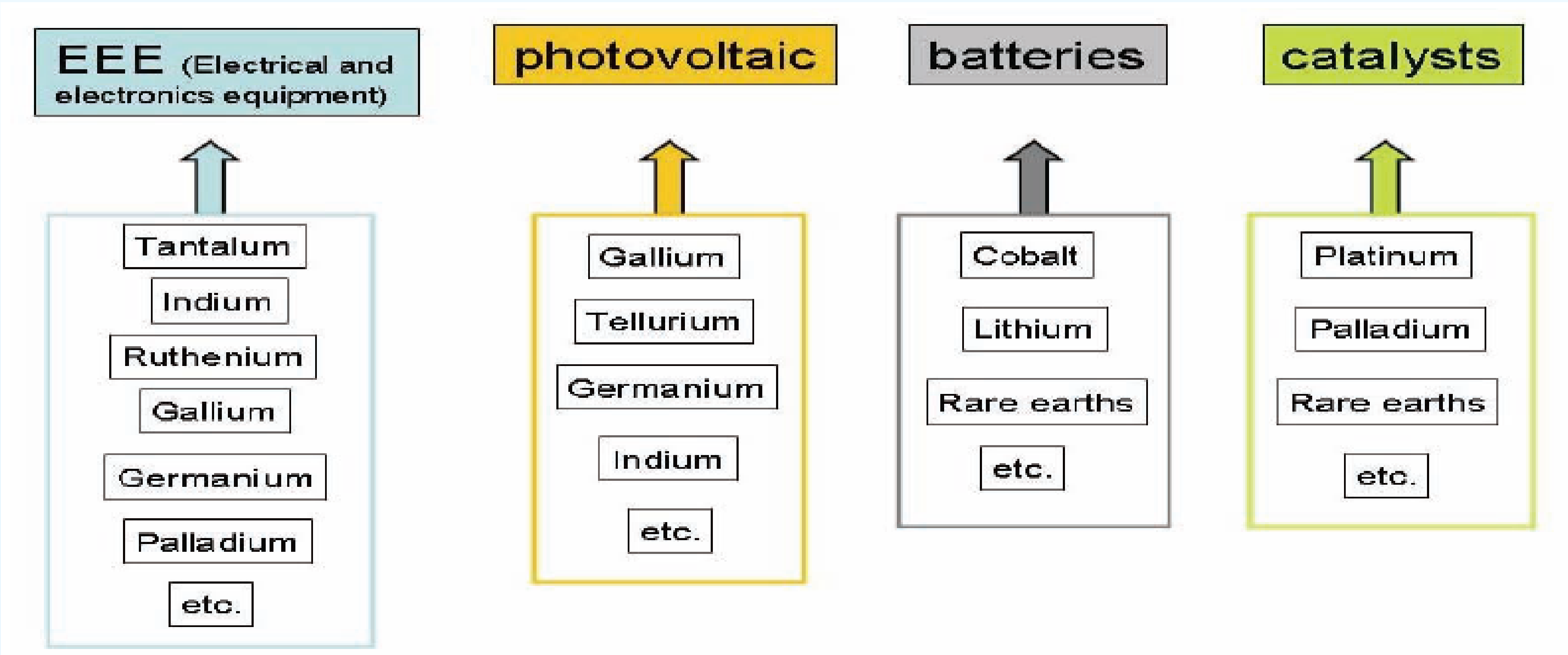
The Promise of Clean Energy Applications for REPM

Applications		Typical Quantity of REO per unit
Traditional – disc drives, personal electronic devices, etc.		Grams
Hybrid and electric vehicles – direct drives and electric assist motors		Kilograms
Direct Drive Wind Turbines		Metric Ton

http://www.reitausa.org/storage/Challenges%20Facing%20New%20Global%20Rare%20Earth%20Separation%20Plants.pdf

GENERAL COMMENTS

- Some of these minerals are economically found in only 1-3 deposits in the world
- Some of these minerals are found in areas of the world that may not be economically unstable or particularly friendly to the U.S.
  - Minerals that provide major revenue to armed fractions for violence, such as that occurring in the Democratic Republic of Congo (GSA, Nov. 2010)
- Some of these minerals come only from the refining of metal deposits and are dependent upon that production
  - Many Cu and Au deposits utilize heap leach technology, which leaves other potential minerals unrecovered in the heap leach

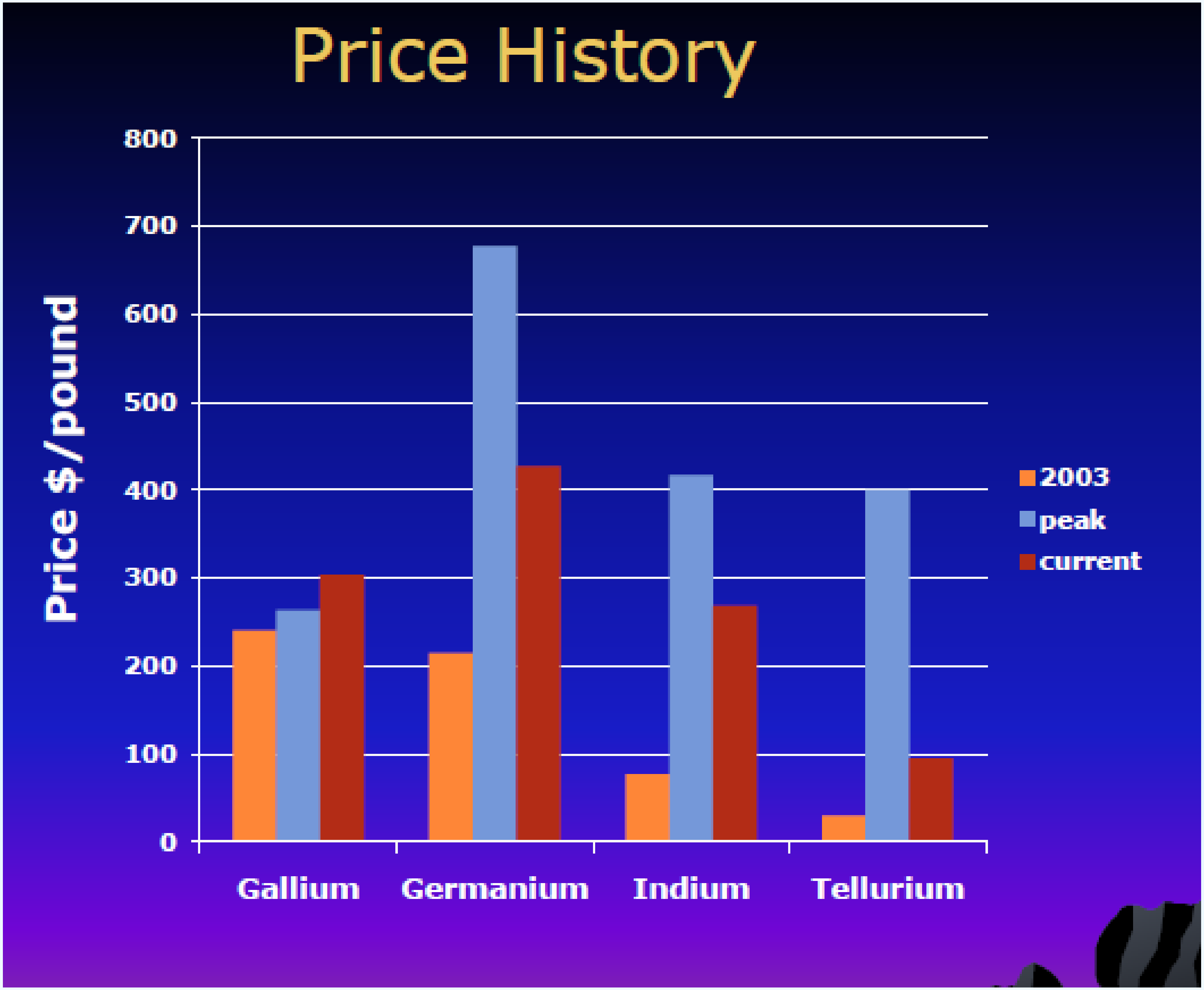


Competing industries/uses

Key Issues with Critical Metals

- Supply Concentration due to deposit nature and location
- Supply Concentration due to government subsidies
- Cartel style supply management – quotas and stockpiles
- Resource nationalism – domestic downstream beneficiation
- Long term cost volatility & price uncertainty
- Complex recovery processes – chemical plants
- State controlled capital investment
- Small size of market for some metals & the dread of over-supply
- End product Innovation as demand driver
- Policy as disruptive demand driver
- Efficiency innovation & Jevon's Paradox
- Substitution as demand destroyer
- Failure of just-in-time procurement strategy
- Opportunity Cost: geopolitical, domestic, end-user
- The Upstream Solution
- The Downstream Solution

http://www.slideshare.net/Tehama/john-kaiser


Price History
Price $/pound
800
700
600
500
400
300
200
100
0
Gallium
Germanium
Indium
Tellurium
2003
peak
current

- Analytical labs are swamped (i.e., too long) and expensive
- There is a need for relatively quick, inexpensive methods to delineate drill hole targets
- Developing a procedure using a portable X-ray fluorescent instrument to use in drilling, stream sediment and soil surveys, to aid in exploration and ore control

5 Dimensions of Mineral Availability

WHAT Questions Must We Ask?

1 **Geologic** Availability

✓Does the mineral resource exist?

2 **Technical** Availability

✓Can we extract and process it?

3 **Environmental & Social** Availability

✓Can we produce it in environmentally and socially responsible and acceptable ways?

4 **Political** Availability

✓How do governments influence availability through their policy and actions?

5 **Economic** Availability

✓Can we produce it at a cost users are willing and able to pay?

Text adapted from *"Minerals, Critical Minerals, and the U.S. Economy"* by the National Research Council of the National Academies

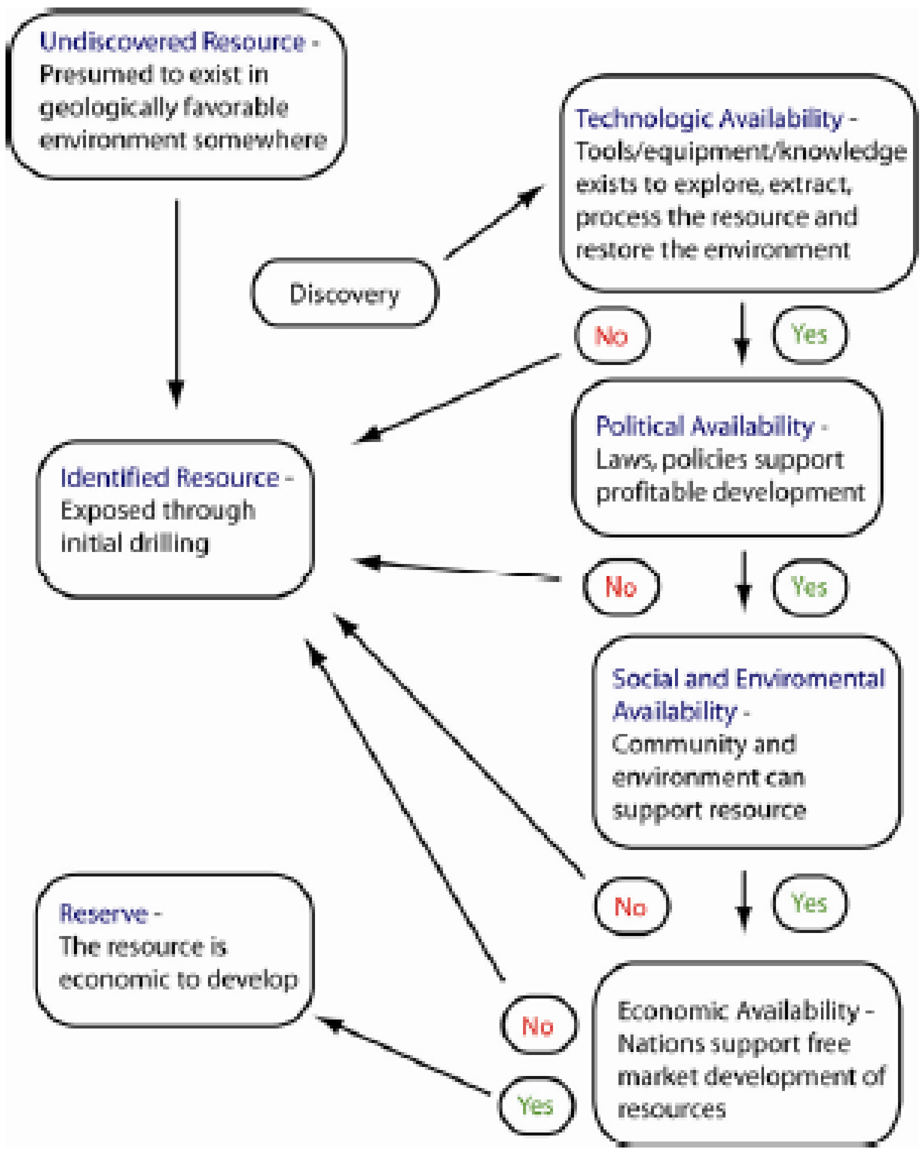


FIGURE 3.6. The availability of a mineral resource is dynamic in the five dimensions of geologic, technologic, social and environmental, political, and economic availability. Only if the extraction and processing of the resource is proved to be economically profitable is it considered a reserve.

http://www.nma.org/pdf/101606_nrc_study.pdf

Criticality Index

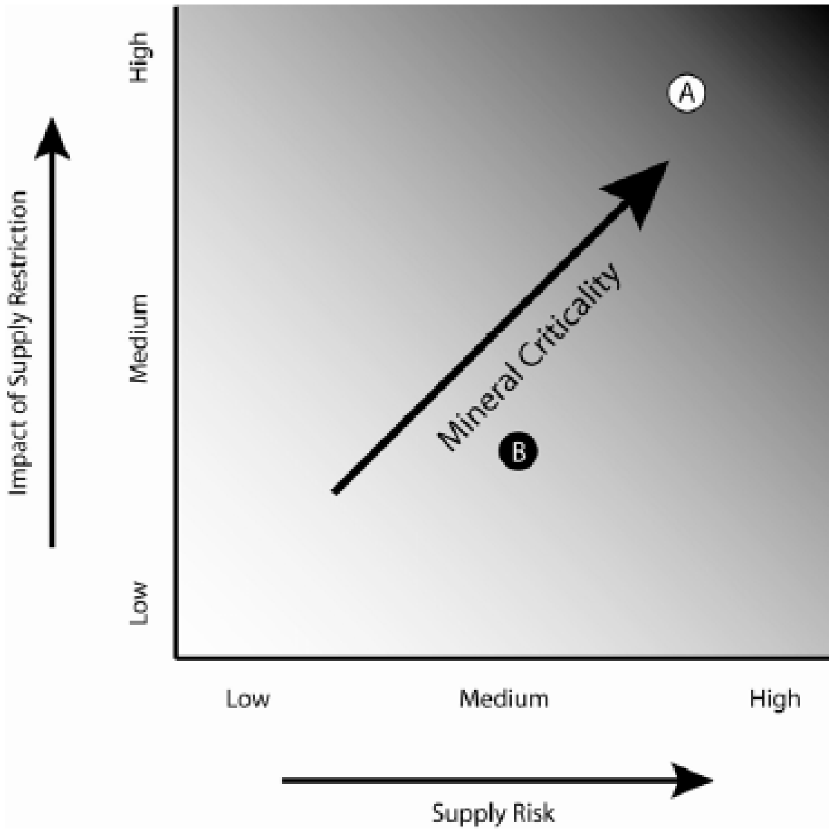
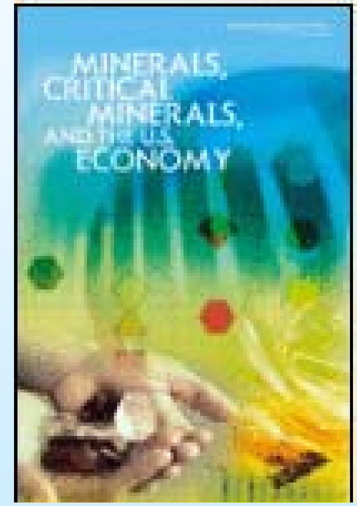
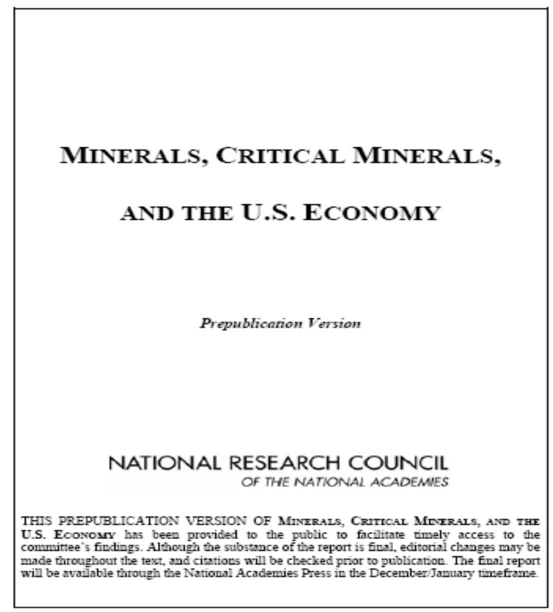


FIGURE 1.3 The criticality matrix as established in this report allows evaluation of the "criticality" of a given mineral. A specific mineral or mineral product can be placed on this figure after assessing the impact of the mineral's supply restriction should it occur (vertical axis) and the likelihood of a supply restriction (horizontal axis). The degree of criticality increases as one moves from the lower-left to the upper-right corner of the figure. In this example, Mineral A is more critical than Mineral B. More specific descriptions of the parameters used to evaluate mineral supply restrictions and their impacts are presented in Chapters 2-4.





MINERALS, CRITICAL MINERALS,

AND THE U.S. ECONOMY

Prepublication Version

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

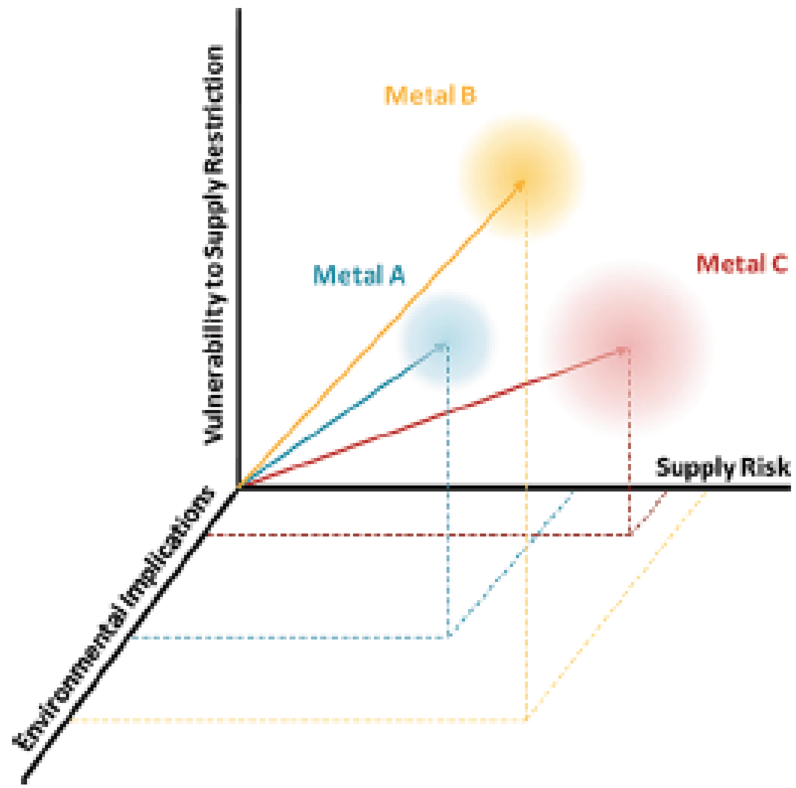
THIS PREPUBLICATION VERSION OF MINERALS, CRITICAL MINERALS, AND THE U.S. ECONOMY has been provided to the public to facilitate timely access to the committee's findings. Although the substance of the report is final, editorial changes may be made throughout the text, and citations will be checked prior to publication. The final report will be available through the National Academies Press in the December/January timeframe.

http://www.nma.org/pdf/101606_nrc_study.pdf

Criticality is context specific:

- What is critical for a given manufacturer or product may not be critical for another, what is critical for a state may not be critical for a country, and what is critical for national defense may be different than what is necessary to make a television brighter or less expensive.

- Recent studies have expanded the scope of criticality to include environmental and technological factors.



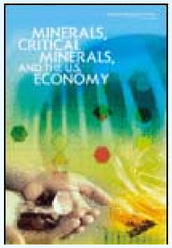
Graedel, T. E.; Barr, R.; Chandler, C.; Chase, T.; Choi, J.; Christoffersen, L.; Friedlander, E.; Henly, C.; Nassar, N. T.;Schechner, D.; Warren, S.; Yang, M.; Zhu, C., 2012, Methodology of metal criticality determination: Environ. Sci. Technol., 46, 1063• 1070.

USGS

Table 1. Relevant Material-Related Characteristics for Different Organizational Levels

		using corporation	using nation	global
1	focus	relevance to that firm's product line	relevance to national industry and population	all uses of a material, wherever they happen
2	time scale	1−5 years	5−10 years	10−100 years
3	supply potential	crucial	very important	very important
4	technological change	very important	worth consideration	impossible to predict
5	geopolitical factors	crucial	important	unimportant
6	social factors	moderately important	very important	unimportant
7	environmental implications	important	important	moderately important
8	intensity of competition	crucial	depends on national industry composition	unimportant

Graedel, T. E.; Barr, R.; Chandler, C.; Chase, T.; Choi, J.; Christoffersen, L.; Friedlander, E.; Henly, C.; Nassar, N. T.;Schechner, D.; Warren, S.; Yang, M.; Zhu, C., 2012, Methodology of metal criticality determination: Environ. Sci. Technol., 46, 1063–1070.



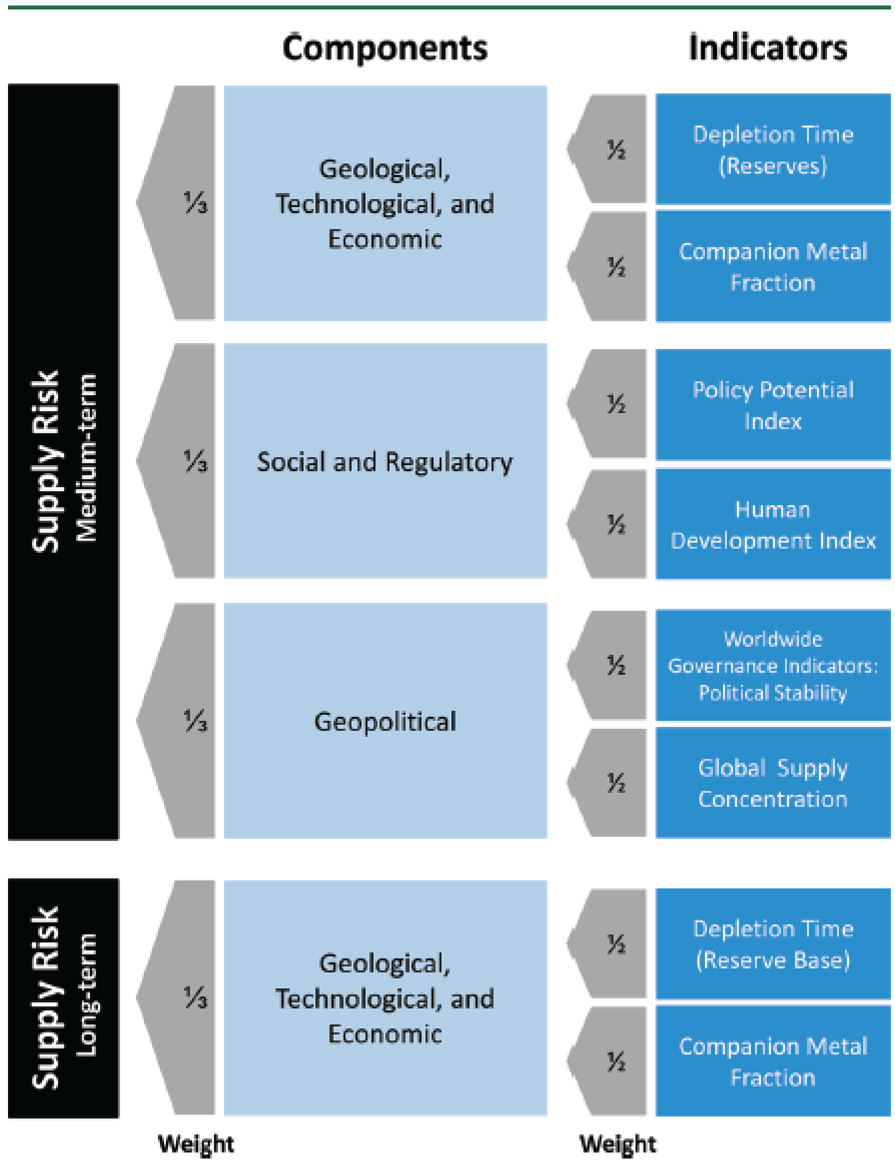
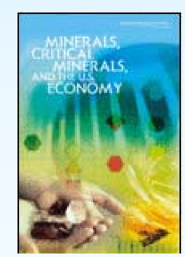
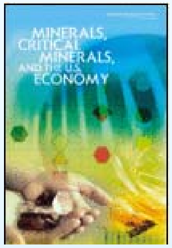


Figure 1. Diagram of the supply risk axis, its components, and its constituent indicators, for the medium-term perspective, used mainly in conjunction with the corporate- and national-level assessments and, for the long-term perspective, used mainly in conjunction with the global-level assessment.

Graedel, T. E.; Barr, R.; Chandler, C.; Chase, T.; Choi, J.; Christoffersen, L.; Friedlander, E.; Henly, C.; Nassar, N. T.;Schechner, D.; Warren, S.; Yang, M.; Zhu, C., 2012, Methodology of metal criticality determination: Environ. Sci. Technol., 46, 1063• 1070.





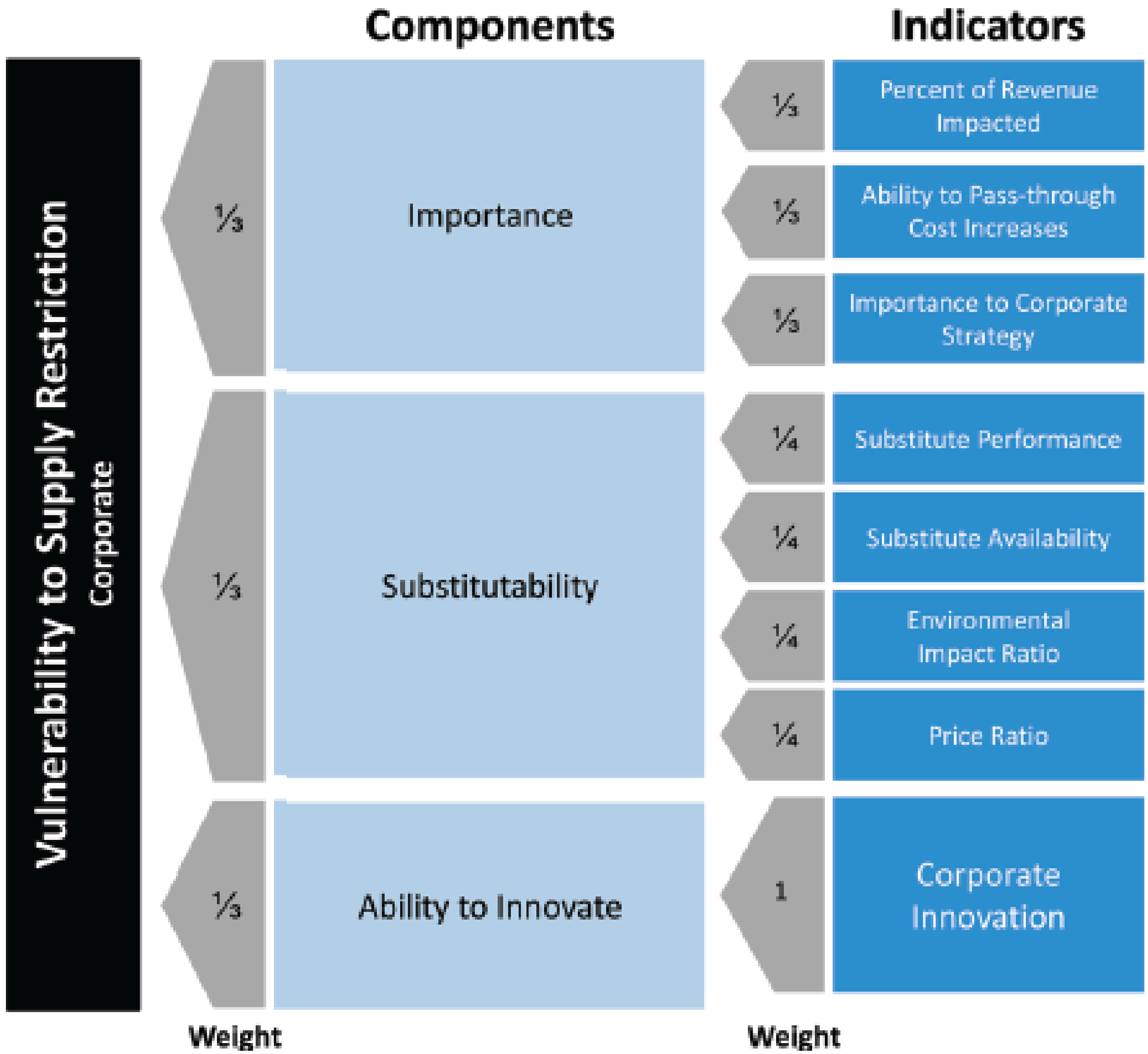


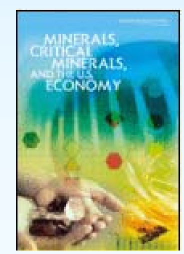
Figure 2. Components of the valuation methodology for the vulnerability to supply restriction, corporate level.

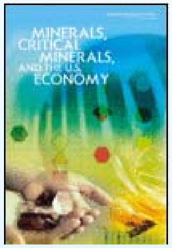
Graedel, T. E.; Barr, R.; Chandler, C.; Chase, T.; Choi, J.; Christoffersen, L.; Friedlander, E.; Henly, C.; Nassar, N. T.;Schechner, D.; Warren, S.; Yang, M.; Zhu, C., 2012, Methodology of metal criticality determination: Environ. Sci. Technol., 46, 1063• 1070.

Table 2. Corporate-Level Vulnerability to Supply Restriction Matrix[a]

Component		Importance			Substitutability				Ability to Innovate
Indicator		Percentage of Revenue Impacted	Ability to Pass-through Cost Increases	Importance to Corporate Strategy	Substitute Performance	Substitute Availability	Environmental Impact Ratio	Price Ratio	Corporate Innovation
Score	87.5 (75-100)	> 5%	Practically impossible	Essential	Poor	Supply Risk score of substitute	See equation in SI	See equation in SI	Poor
	62.5 (50-75)	>2.5-5%	Difficult	Very important	Adequate				Adequate
	37.5 (25-50)	0.5-2.5%	Possible	Moderately important	Good				Good
	12.5 (0-25)	< 0.5%	Relatively easy	Less important	Exemplary				Exemplary

Graedel, T. E.; Barr, R.; Chandler, C.; Chase, T.; Choi, J.; Christoffersen, L.; Friedlander, E.; Henly, C.; Nassar, N. T.;Schechner, D.; Warren, S.; Yang, M.; Zhu, C., 2012, Methodology of metal criticality determination: Environ. Sci. Technol., 46, 1063• 1070.





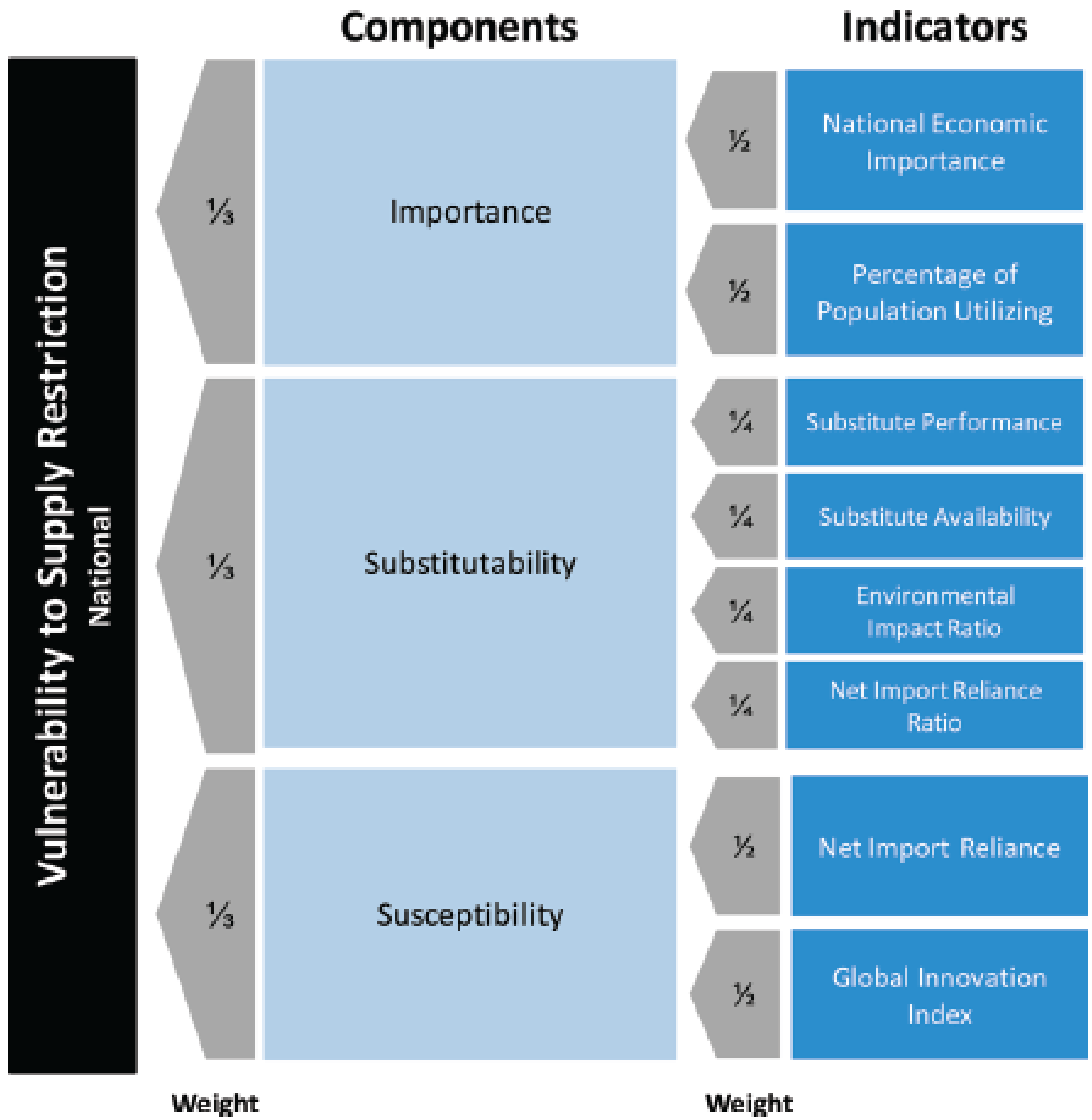
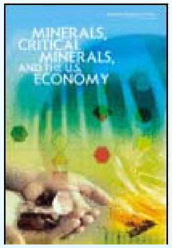


Figure 3. Components of the valuation methodology for the vulnerability to supply restriction, national level.

Graedel, T. E.; Barr, R.; Chandler, C.; Chase, T.; Choi, J.; Christoffersen, L.; Friedlander, E.; Henly, C.; Nassar, N. T.;Schechner, D.; Warren, S.; Yang, M.; Zhu, C., 2012, Methodology of metal criticality determination: Environ. Sci. Technol., 46, 1063• 1070.



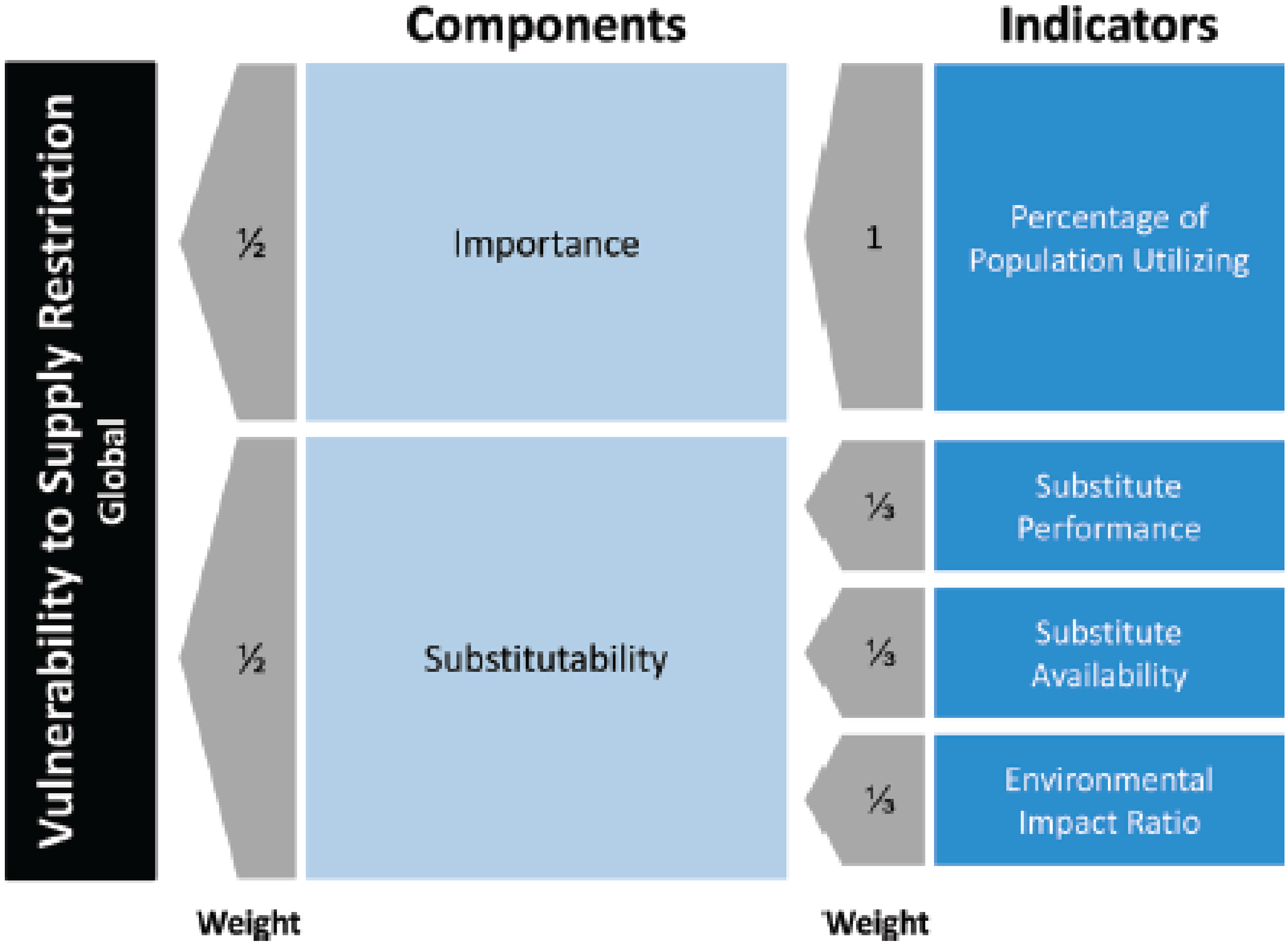


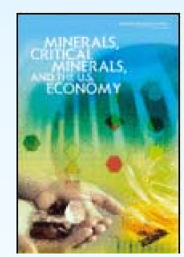
Figure 4. Components of the valuation methodology for the vulnerability to supply restriction, global level.

Graedel, T. E.; Barr, R.; Chandler, C.; Chase, T.; Choi, J.; Christoffersen, L.; Friedlander, E.; Henly, C.; Nassar, N. T.;Schechner, D.; Warren, S.; Yang, M.; Zhu, C., 2012, Methodology of metal criticality determination: Environ. Sci. Technol., 46, 1063•1070.

TABLE 4.2 Scoring the Vertical Axis of the Criticality Matrix for Example Mineral X

Application Group (End Uses) for Mineral X	Proportion of Total U.S. Market for Mineral X in Application	Impact of Supply Restriction (Values of 1 to 4)	Weighted Score (Product of Columns 2 and 3)
Aerospace propulsion	0.27	4	1.08
Pigments	0.65	4	2.60
Biomedical devices	0.8	2	0.16
Overall importance in use	1.00[a]	n.a.	3.84[b]

[a] Total proportion will always equal 1.
[b] Final weighted score.
NOTE: n.a. = not applicable.



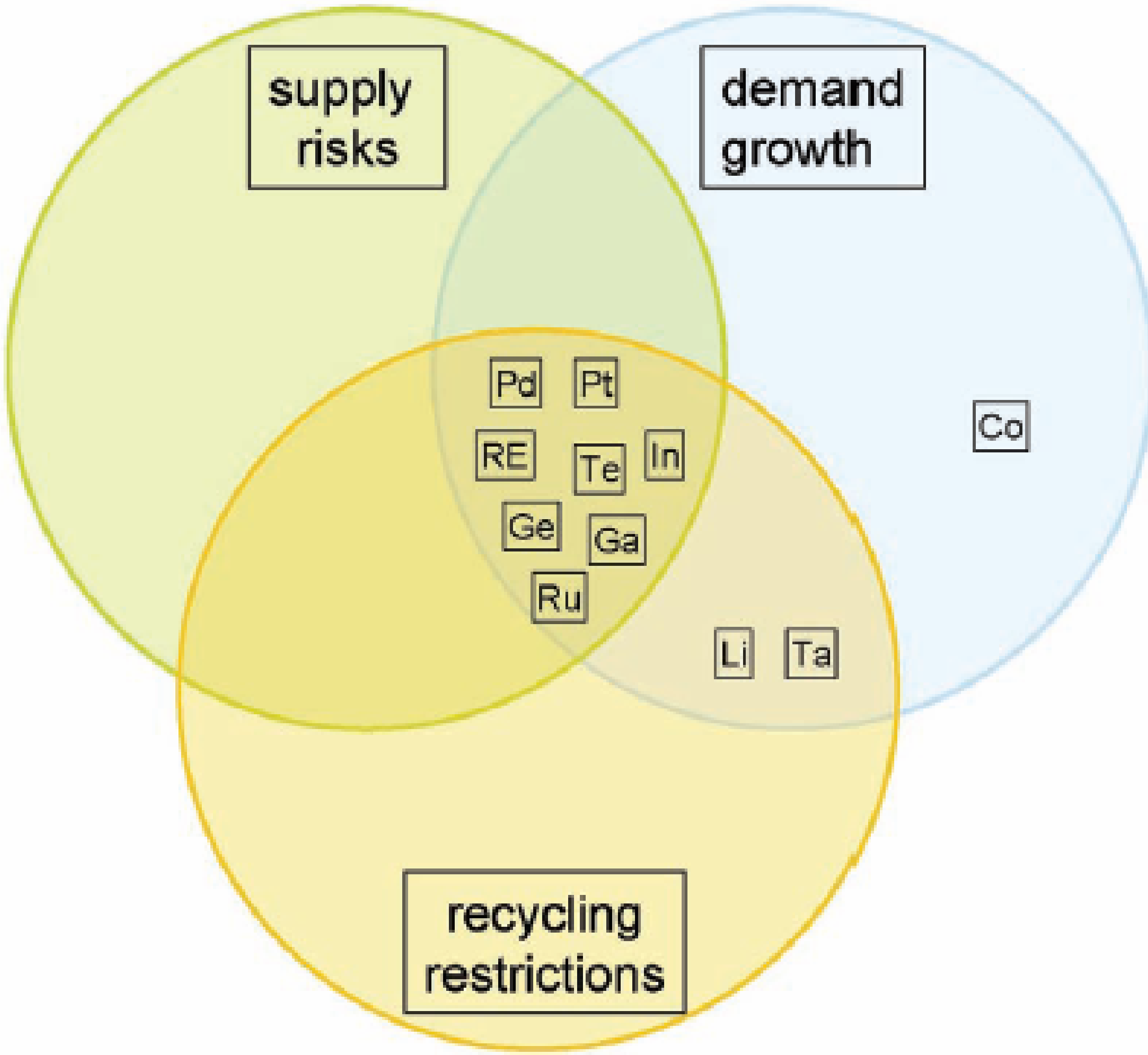


Figure 7.1: Prioritization step 1: general assignment of critical metals

	Rapid demand growth > 50% increase of total demand until 2020	Moderate demand growth > 20% increase of total demand until 2020
Tantalum	+	
Indium	+	
Ruthenium	+	
Palladium	+	
Platinum	+	
Rare earths	+	
Gallium	+	
Tellurium	+	
Germanium		+
Cobalt		+
Lithium	+	

Figure 7.2 Prioritization step 2: Distinction of rapid/moderate demand growth

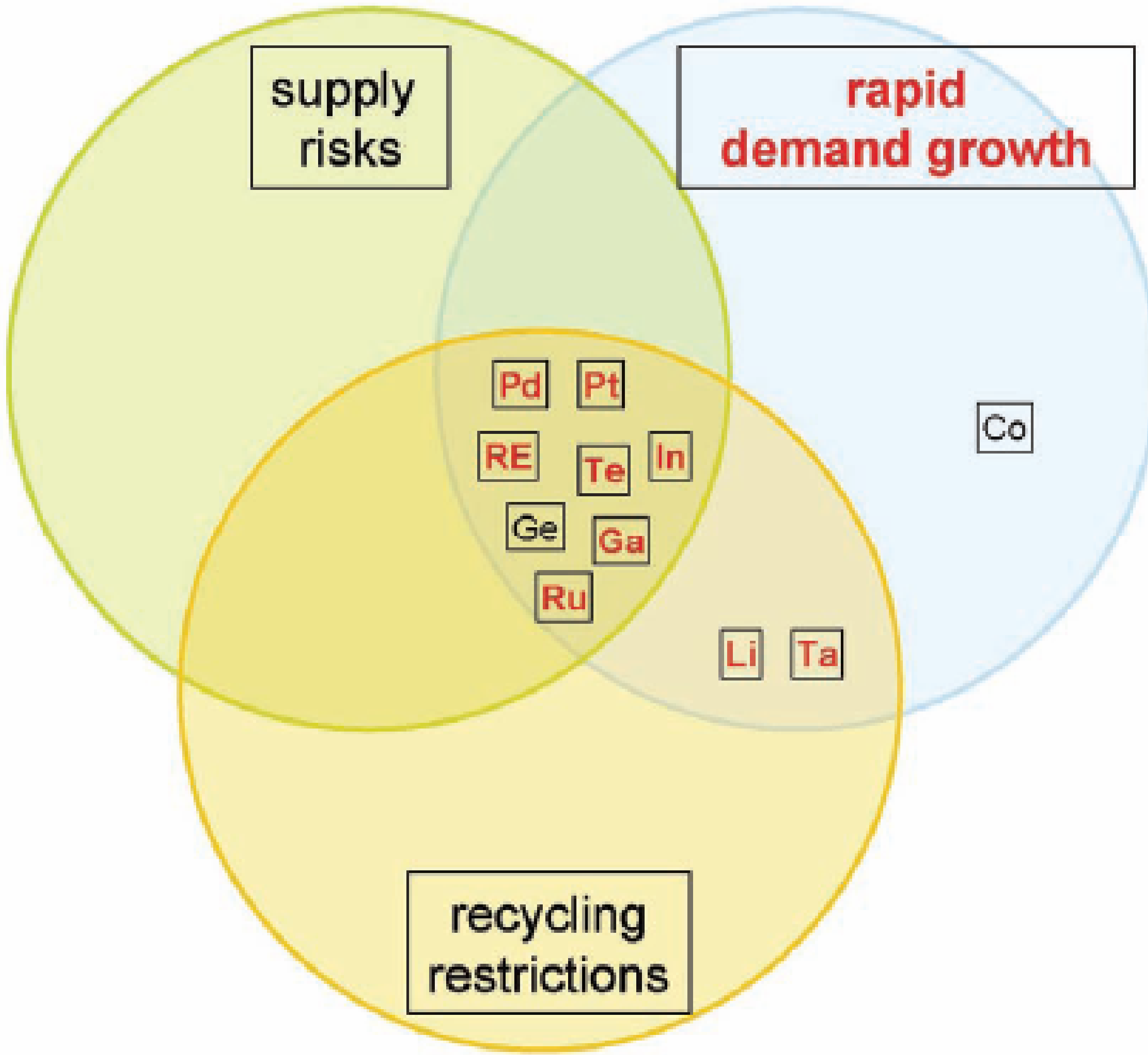


Figure 7.3: Visual transfer of differentiated growth rates for demand

	Regional concentration of mining >90% share of global mining in the 3 mayor countries	**Physical scarcities** reserves compared to annual demand	**Temporary scarcity** Time lag between production and demand	**Structural or technical scarcity** Metal just a minor or by-product
Tantalum	-	-	+-	-
Indium	-	+	+-	+
Ruthenium	+	-	+-	-
Palladium	+	-	+-	-
Platinum	+	-	+-	-
Rare earths	+	-	-	-
Gallium	-	-	+	+
Tellurium	-	+-	+	+
Germanium	-	+- (?)	+- (?)	+
Cobalt	-	-	-	+-
Lithium	-	-	+-	-

Figure 7.4: Prioritization step 3: Focused distinction of supply restriction

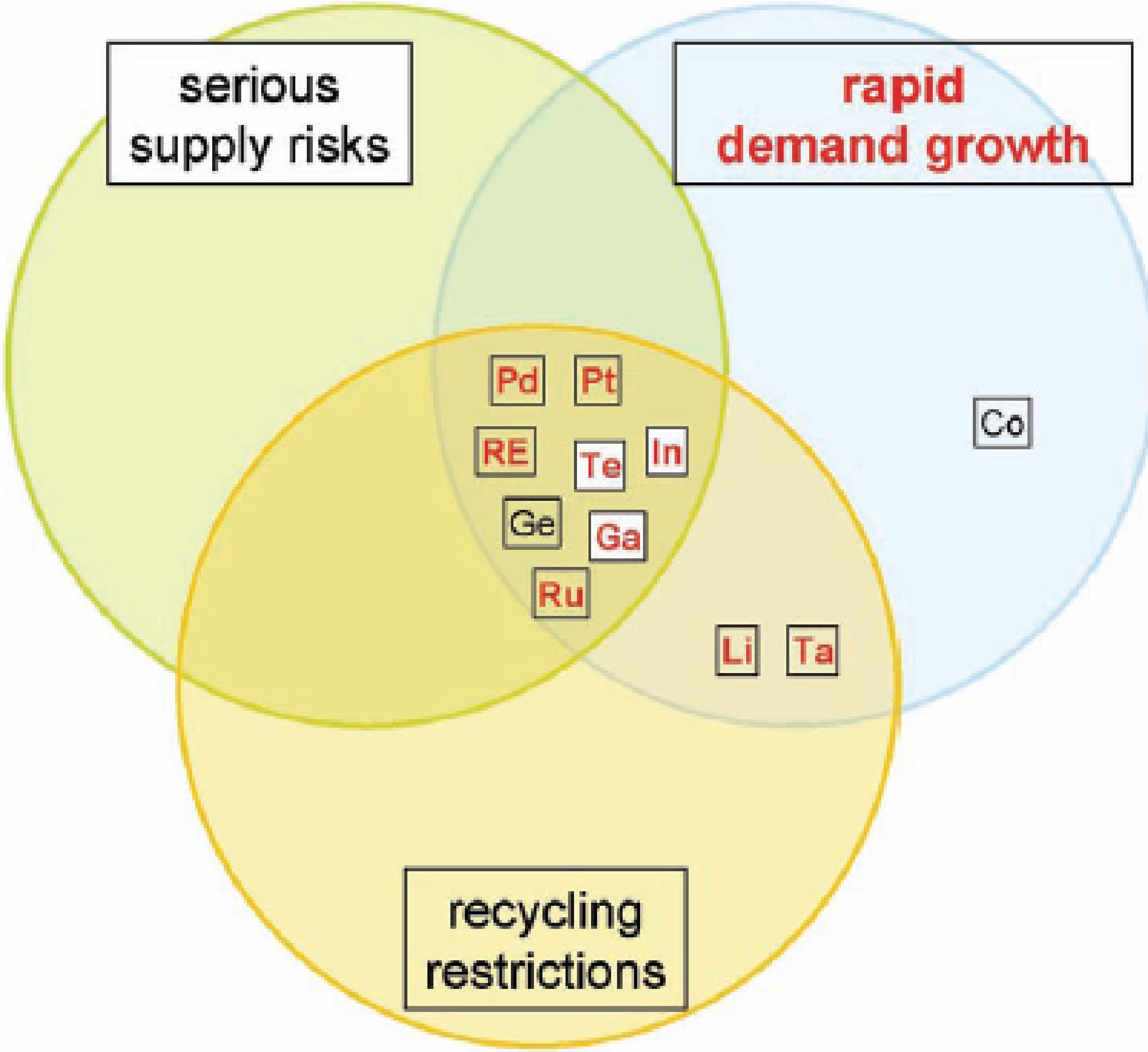


Figure 7.5: Visual transfer of differentiated supply restrictions

7.4 Focused prioritization regarding recycling (4th step)

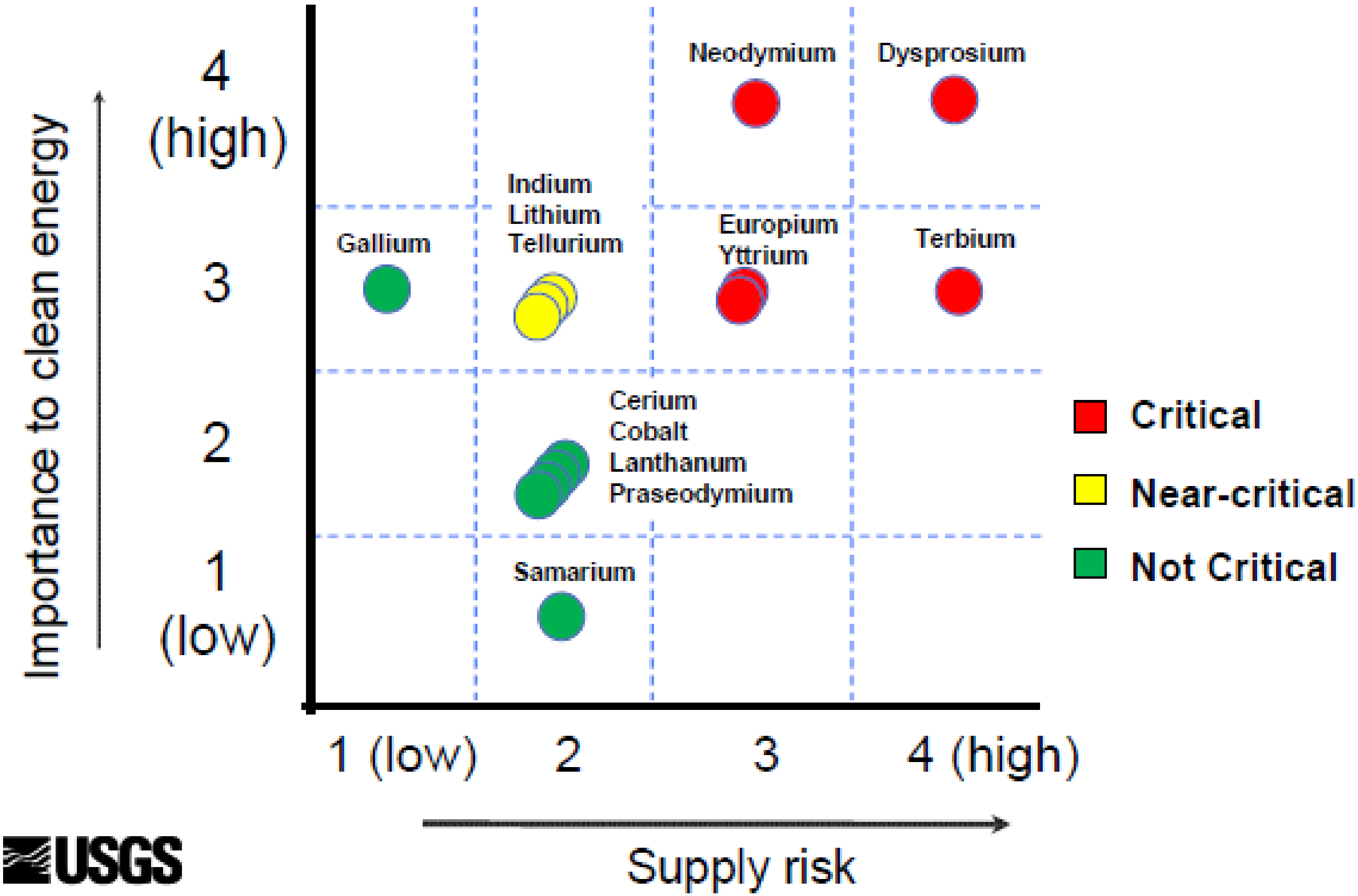
	High scale of dissipative applications	Physical/chemical limitations for recycling	Lack of suitable recycling technologies and/or recycling infrastructure	Lack of price incentives for recycling
Tantalum	+	+	+	-
Indium	+	-	+-	-
Ruthenium	+	-	+-	-
Palladium	+-	-	+-	-
Platinum	+-	-	+-	-
Rare earths	+-	+	+	-
Gallium	+	-	+-	-
Tellurium	+	-	-	-
Germanium	+	-	+-	-
Cobalt	+-	-	-	-
Lithium	+-	+	+	+

Figure 7.6: Prioritization step 4: Focused distinction of recycling restrictions

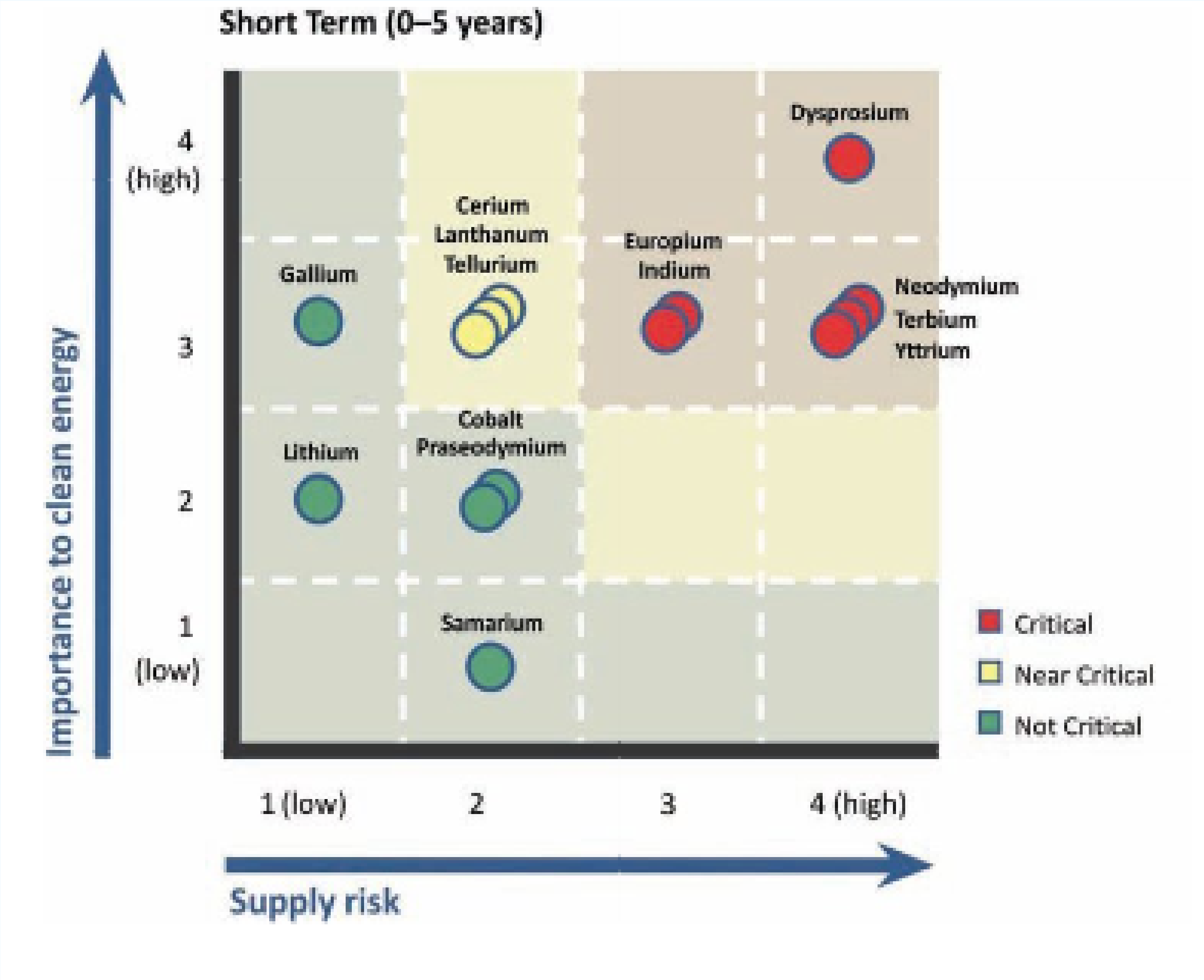
timeline	Metal
short-term (within next 5 years) + **rapid** demand growth + **serious** supply risks + moderate recycling restrictions	Tellurium Indium Gallium
mid-term (till 2020) + **rapid** demand growth and + **serious** recycling restrictions or: + moderate supply risks + moderate recycling restrictions	Rare earths Lithium Tantalum Palladium Platinum Ruthenium
long-term (till 2050) + moderate demand growth + moderate supply risks + moderate recycling restrictions	Germanium Cobalt

Figure 7.8: Summarized prioritization regarding timeline of this study

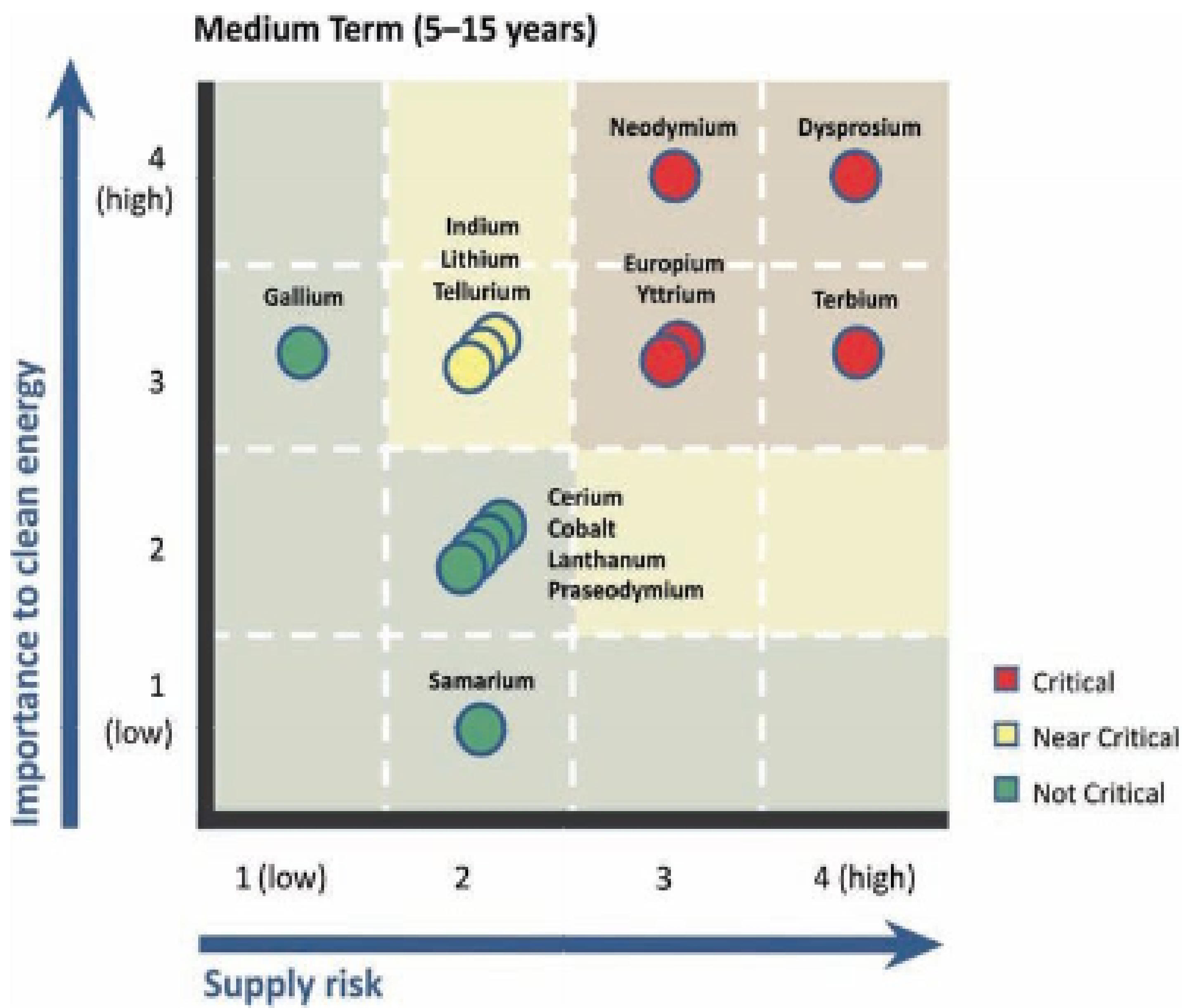
Energy critical elements as defined by DOE (2011)



USGS



Short Term (0–5 years)
Importance to clean energy
4 (high)
3
2
1 (low)
Dysprosium
Cerium
Lanthanum
Tellurium
Europium
Indium
Gallium
Neodymium
Terbium
Yttrium
Cobalt
Praseodymium
Lithium
Samarium
Critical
Near Critical
Not Critical
1 (low)
2
3
4 (high)
Supply risk


Medium Term (5–15 years)
Importance to clean energy
4 (high)
3
2
1 (low)
Neodymium
Dysprosium
Indium
Lithium
Tellurium
Europium
Yttrium
Gallium
Terbium
Cerium
Cobalt
Lanthanum
Praseodymium
Samarium
Critical
Near Critical
Not Critical
1 (low)
2
3
4 (high)
Supply risk

Critical and strategic minerals will change with time.

1) What is the global demand likely to be?
2) What is the US supply likely to be?
3) What are the limits and obstacles to US production?
   a) land access
   b) permitting speed
4) What needs to be done to convert marginal resources into reserves?
6) What are the new types of deposits and ore-forming systems of the future?

Some of the challenges in producing these technologies

- How much of these minerals do we need?
- Are there enough materials in the pipeline to meet the demand for these technologies and other uses?
- Can any of these be recycled?
- Are there substitutions that can be used?
- Are these minerals environmental friendly—what are the reclamation challenges?
  - REE and Be are nearly always associated with U and Th and the wastes from mining REE and Be will have to accommodate radioactivity and radon

Bottlenecks

- Risk and timing of investment
  - Unpredictable
  - Rapid change in demand
  - Engineering/design/production of these products is faster then the exploration/mining/processing
- Extraction
  - Supplies
  - Economically feasible in a timely manner
- Refining
  - Technically feasible
  - Economical

FUTURE GEOLOGICAL RESEARCH

- Need for understanding the mineralogy and distribution of these minerals in known ore deposits
  - Geologic mapping (lithology, structure, alteration)
  - Geologic deposit models
  - Mineralogy/chemistry
- Are there additional geologic sources for some of these minerals?
- What are the potential environmental consequences of mining these minerals and how do we mitigate them?

ASSIGNMENT

- **NEXT WEEK (Feb 12) IS Be, REE AFTER THAT (Feb 19, March 5, 12)**
- Barton and Young, S., 2002, Non-pegmatitic deposits of beryllium: mineralogy, geology, phase equilibria and origin: Reviews in Mineralogy and Geochemistry, v. 50, p. 591-691. http://www.geo.arizona.edu/~mdbarton/MDB_papers_pdf/Barton02_BeRiMG050.pdf
- McLemore, 2010, NMBGMR OF 533, http://geoinfo.nmt.edu/publications/openfile/downloads/OFR500-599/526-550/533/ofr_533.pdf